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DEVELOPMENT OF ELECTRICAL SWITCHGEAR FOR SPACE NUCLEAR ELECTRICAL SYSTEMS

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SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

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Quarterly Progress Report No. 2

Covering the Period
March 4 to June 4, 1965

Edited by:

A. H. Powell
Program Manager

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-6467

Technical Management
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FOREWORD

This report describes work which is being performed by the General Electric Company under Contract NAS 3-6467 from the National Aeronautics and Space Administration. The objective, as outlined in the contract, is to develop and design ground prototype AC Circuit Breakers and DC Engine Contactors, suitable for, and tested under, expected launch and space requirements. The Breakers will be rated 1000 volts, 600 amperes, 2000 cps, while the DC Contactors will have a rating of 10,000 volts, 10 amperes.

Management of the program for General Electric Company has been assigned to A. H. Powell, Manager-Electrical Systems, Space Power and Propulsion Section with R. N. Edwards, Consulting Engineer, providing technical guidance and advice where desirable. Project Engineer for the program is E. F. Travis of the Advanced Technology Laboratory. Contributors to this report, in addition to Messers Powell, Edwards, and Travis, include D. S. Engleby, G. Gati, and W. W. Shoemaker of SPPS, and J. L. Goldberg, G. W. Kessler, and Mrs. N. Fitzroy of ATL.

Mr. E. A. Koutnik of the National Aeronautics and Space Administration is the Technical Manager for this contract.

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I. INTRODUCTION

This program is a continuation of the Electrical Switchgear development and investigation work which was completed under Contract NAS 3-2546 (final report NASA-CR-54247) with the successful interruption using a demountable vacuum unit, of over 20 amperes DC at 10,000 volts, and over 1800 amperes at 1200 volts, 2000 cycles per second.

The goals for this program were established so as to provide devices that would be suitable for planned Nuclear Space Power Systems of 1 to 4 megawatts capacity. The AC Breakers are being designed to have a rating of 600 amperes continuous current, and voltage of 1000 rms at 2000 cycles per second. The other device under development is of similar configuration except it will be rated to function as a contactor for an ion engine and be able to carry 10 amperes at 10,000 volts DC.

Development effort will result in ground prototype Breakers and Contactors which will be designed to meet launch environment mechanical tests (vibration, shock, acceleration, and acoustical noise) as well as space conditions of pressure, temperature, and radiation. Furthermore, the devices are to successfully interrupt the expected overload and short circuit conditions that will be encountered in the space power system.

While Program Management is centered in the Space Power and Propulsion Section of the General Electric Company in Evendale, major development work is being carried on by the Advanced Technology Laboratory in Schenectady with important technical and test assistance from other Laboratories and Departments, especially Power Tubes and Switchgear.

II SUMMARY

The second quarterly period of this program resulted in firming of the design for the actuator mechanism, the selecting of interrupter enclosure materials, and determining basic concepts for the interrupter unit. Overall program status was reviewed at two points during the quarter in meetings with NASA representatives, Messers Cummings and Koutnik on April 6, and Messers Shumaker and Koutnik on May 28. Both meetings were held at the Advanced Technology Laboratories.

A summary of specific action and results are given below, based on the detailed information in the body of this report. A sketch of the overall breaker in accordance with the design concepts at the close of this report period, is included as Figure 1.

Vacuum Interrupter

- A comprehensive series of gas evolution tests conducted on four candidate metals for the enclosure resulted in the selection of Rodar, a Ni-Fe-Co alloy, as the best and easiest to fabricate.

- A 0.5 liter per second ion pump will probably be required to maintain adequate pressure, but such a device must be cooled to approximately 200°C to maintain hydrogen pumping speed. Initial check of the proposed pump under vibration conditions showed no failures.

• Further theoretical review of the molybdenum contact design provided background data which indicates that the points of contact will approach melting temperatures, especially during the brief period while closed before opening under short circuit conditions.

• Check tests on the contacts in the Phase I test capsule showed a resistance of 0.0003 ohms at room temperature increasing to 0.001 ohms at 750°C, the estimated contact temperature when carrying 600 amperes. The data serves to confirm the theoretical review.

• Detailed study of heat transfer problems due to the high contact temperature led to a design concept to provide:

1. High heat removal by radiation from the 1000 volts, 600 ampere AC circuit breaker, with insulation for 5000 volt surges.
2. Low heat removal from the DC engine contactor, with insulation for 15,000 volts high potential test.

• The basic vacuum interrupter unit or capsule will be designed to be adaptable to both the AC Breaker and DC Contactor.

• Detail drawings of all the alumina insulation have been made and consultation on the design has been started with vendors regarding fabrication and possible cost reduction.

Mechanism

- The toggle actuator was redesigned to reverse the fixed point of attachment, thus reducing length and cost.

- Detail layout drawing of the final design (#587E474) has been completed and issued. Detail drawings of the parts have been started.

- An operating model of the actuator was built for the May 28 review meeting.

- Development work on the solenoid guide diaphrams is continuing, with several series of vibration tests using simulated mechanisms pointing the way to necessary modifications.

Test Plans, Facilities, Schedules

- Circuit parameters for the interruption tests were checked and test procedure plans started, based on making such tests in a 1000°F oven filled with argon, at atmospheric pressure.

- Facilities for mechanical tests are being reviewed, prior to developing test procedures.

- Heat run and endurance tests will be made in a special oven which will mount in the vacuum test chamber at SPPS. The oven design was completed, parts ordered, and fabrication started.

- The PERT diagram was revised to indicate more thorough component testing and show more detail in the fabrication and testing program. Overlap of various phases of the testing program will result in completion of the final tests within the originally scheduled month, even though solving of design problems has extended the release of the parts to fabrication.

During the next quarterly period, all details for both Breaker and Contactor will be completed and materials ordered. Additional preliminary component testing will be done, and plans for testing prepared.

III VACUUM INTERRUPTER

The heart of the Circuit Breaker and the Contactor is the vacuum interrupter or switch. This unit is to be completely sealed from the atmosphere or space, mounted in a structure for operation by a mechanism, with attachments to conduct the current to and from the unit and to dissipate generated heat to a bulkhead or heat sink.

This section of the report will describe the work that has been done in determining the interrupter enclosure material, in developing the contacts, and in designing the overall unit.

A. Enclosure Material

The vacuum interrupter enclosure is made up of a ceramic insulating tube, a metallic end for the fixed contact, and metallic bellows supporting the moving contact. The insulating tubes will be made of a high temperature Alumina similar to that which was used for the Phase I test capsules. The metal for the end pieces and bellows, however, has required special attention because the large surfaces could cause gas evolution problems and loss of the high vacuum during high temperature operation.

The first quarterly report gave the background information which led to the selection of four possible candidate materials that would be most suitable for the enclosure. The selection was based on a number of primary requirements, i.e., (1) the candidate alloys should not contain high vapor pressure constituents such as chromium, manganese, etc., (2) the alloys should be limited to those having a history of vacuum processing for minimum initial gas content, (3) the alloys should be readily formed and joined, (4) the alloys should retain reasonable strength and oxidation resistance at the proposed 500°C or higher operating temperature, and (5) they should be readily available at reasonable cost. Four materials tentatively selected most nearly met these requirements. These were:

1) High purity Molybdenum per AMS 7801.
2) Thoria-dispersed Nickel per General Electric Specification B50T97.
3) High purity Titanium per General Electric Specification B50T1.
4) A Nickel-Cobalt-Iron alloy per General Electric Specification B7Y36 (called Rodar).

These materials, some of which were vacuum melted, are frequently processed in atmospheres which could result in some degree of gas contamination. Therefore, the program described below was designed to define the treatment which, when applied to the appropriate material, would produce the minimum gas content compatible with anticipated service requirements.

1. Outgassing Procedure

The specimens of the candidate materials were outgassed in an ultrahigh vacuum system, shown in Figure 2, which was capable of holding a vacuum of 10^{-8} Torr at the processing temperatures. The specimens (see Figure 3) of Titanium, TD Nickel, Molybdenum, and B7Y36, hereinafter called Rodar (the W. B. Driver Company name applied to B7Y36 composition) were contained in buckets made from Columbium - 1% Zirconium alloy partioned to isolate each material from the other, and suspended in the heating zone. The columbium alloy was expected to "getter" some of the gases evolving from the material being processed. Heat to the specimens was supplied with a resistively heated tantalum heater shielded to reduce the heat loss to the vacuum chamber. Four heater and specimen setups were installed in the chamber to permit, simultaneously, two processing times of approximately six and forty-eight hours, respectively, at the two processing temperatures. In this manner only one test setup was involved and the chamber was opened only after completion of all testing. A sketch of the assembly is shown in Figure 3 , and a photograph of the assembled heater chambers is shown in Figure 4 mounted in the chamber of the vacuum system.

Four individual tests were conducted within the same vacuum chamber at between 2×10^{-7} and 5×10^{-8} Torr as follows:

1) Specimens of Titanium, TD Nickel, and Rodar were loaded into a compartmentalized Cb-1%Zr bucket and heated in assembly No. 1 for six hours at $1545^{\circ}F \pm 5^{\circ}$.
2) Specimens of Titanium, TD Nickel, and Rodar were loaded into a second bucket and heated in heater assembly No. 2 for forty-eight hours at $1545^{\circ}F \pm 5^{\circ}$.
3) Specimens of Molybdenum were loaded into a third bucket and heated in heater assembly No. 3 for six hours at $1600^{\circ}F \pm 5^{\circ}$.
4) Specimens of Molybdenum were loaded into a forth bucket and heated in heater assembly No. 4 for forty-eight hours at $1600^{\circ}F \pm 5^{\circ}$.

A vacuum of 5×10^{-6} Torr was maintained as the four heater and specimen assemblies were heated to their respective temperatures. Test time was started when the vacuum reached 5×10^{-7} Torr and every test furnace was at temperature. The vacuum continually improved during the first three hours to 2×10^{-7} Torr. A vacuum of 8×10^{-8} Torr was obtained by the end of the first six hours at which time the two six-hour tests were terminated. The two remaining groups under test were then continued to 48 hours with a terminal vacuum of 5×10^{-8} Torr obtained.

At the conclusion of the outgassing, the samples were allowed to cool to room temperature while still in the high vacuum. They were then placed in clean capsules for delivery to Owensboro for testing.

2. Material Test, Evaluation and Selection

Sample pieces of the four candidate materials in the "as received" condition and after the 6 and 48 hours outgassing treatments, were tested at the General Electric Company Tube Department Technology Facilities at Owensboro, Kentucky. A special mass spectrometer gas measuring apparatus was used to determine the outgassing characteristics of the samples. A total of 36 samples (three thicknesses, of four materials, in the three conditions of treatment) were tested. Furthermore, several additional tests were made using 3 pieces of the thinnest Rodar for a single test, to provide additional data. Throughout the series of tests, data was obtained at selected times on the "background", or gas evolved from the system only, for use in correcting the results with the actual samples.

The mass spectrometer inlet system used for the gas collecting tests is shown in diagram form in Figure 5 . The procedures for a typical test is described below:

The part to be analyzed is handled with tweezers and placed in the bottom of the quartz tube. The tube is then connected to the system with the ground glass joints and a stopcock. The joint at the top of the quartz tube is heated to remove bubbles formed in the apiezon grease used on the seal.

The closed system is then evacuated for 15-20 minutes using the main diffusion pump, and with the mass spectrometer with its pumping means also turned on. A check is made for air leaks, and if none are found the test proceeds.

Valves 1 and 2 are closed to isolate the spectrometer and gas collecting system from the main pump. The furnace heating current and the Peak selector (which selectively applies voltage to the proper collecting plate in the mass spectrometer) are turned on at the same time and gas collection is begun.

Gas flow and composition is measured from that which flows through the small holes in the gold "leak" diaphram. Thus, the system with the cycloid tube provides for a constant sensitivity and a measure of the partial pressure, with periodic check of each of the gas "weights" being considered. The automatic selection process provides a series of data points every 10 seconds for 5 different gasses (H_2-H_2O-CO&N_2-C_2/C_5-CO_2) and the oven temperature, giving one point for each item every minute. The test is continued with the oven (sample) reaching a temperature of 900°C (1000°C for 2 of the three piece tests) in about 18 minutes, after which the sample is held at the top temperature with data being taken for a total of 20 minutes.

This system provides a continuous collection, with each Peak scan showing the total gas evolved up to the particular scan, ie, there is no pumpout of the system. After the analysis, the quartz tube sealed off with stopcock and still evacuated, is removed from the furnace and allowed to cool.

At certain times, preferably at the start and end of a series of tests, a check is made of "background". The same procedure is followed as noted above, except that no sample is put in the quartz tube.

The data which has resulted from the gas collection tests has been corrected to remove the "background" gas, and the results are shown in Tables 1 through 36 in accordance with the following index:

INDEX OF TABLE NUMBER FOR GAS DATA

	Samples - As Received	6 Hours Outgassed	48 Hours Outgassed
Rodar - .010"	1	4	7
.020"	2	5	8
.060"	3	6	9
TD Nickel - .010"	10	13	16
.020"	11	14	17
.060"	12	15	18
Titanium - .010"	19	22	25
.020"	20	23	26
.060"	21	24	27
Molybdenum - .010"	28	31	34
.020"	29	32	35
.060"	30	33	36

The majority of the gas evolved in the heat treated (outgassed) materials, and which is of major concern as far as maintaining the vacuum in the interrupter unit, is Hydrogen. Therefore, the data on the Hydrogen gas evolved during the tests, and given in Tables 1 through 36, has been plotted in curve form in Figures 6 through 17 . Note that total gas and temperature of the samples are plotted against time from start of test. The various materials are shown in the curvesin accordance with the following index:

MATERIAL	FIGURE NUMBER
Rodar - As Received	6
Rodar - 6 Hours Outgassed	7
Rodar - 48 Hours Outgassed	8
TD Nickel - As Received	9
TD Nickel - 6 Hours Outgassed	10
TD Nickel - 48 Hours Outgassed	11
Titanium - As Received	12
Titanium - 6 Hours Outgassed	13
Titanium - 48 Hours Outgassed	14
Molybdenum - As Received	15
Molybdenum - 6 Hours Outgassed	16
Molybdenum - 48 Hours Outgassed	17

A review of the above referenced curves indicate that Rodar and Molybdenum were the only materials which had low gas evolution after vacuum firing (heat treatment - outgassing). Titanium which was considered a good candidate with the throught that it might actually perform as a "getter" for the hydrogen, had to be discarded. While Titanium did getter or absorb hydrogen at high temperature, it evolved the trapped gas right at the design temperature operating range of 450°C to 600°C. TD Nickel contained too much gas, even after the optimum vacuum firing processing.

From a fabrication point of view, it would be preferable to use Rodar rather than Molybdenum for the switch enclosure. Considerable forming and joining will be involved and Rodar is relatively easy to use for this work. Therefore, a detail analysis was made of the gas evolution data to determine if it was within tolerable limits, particularly if a small ion pump of 0.5 liter per second was used on the switch.

The data from the Rodar tests on .010" and .020" thick material, after heat treatment, was taken from Tables 1, 7, and 8 and used to prepare Tables 37, 38, and 39. Data from three additional gas collection tests performed using 3 sample pieces of Rodar at one time, were used to prepare the Tables 40, 41, and 42. An overall index for the 6 hydrogen gas data summary and reduction tables is shown below:

RODAR - THICKNESS AND TREATMENT	TABLE NUMBER
1 Piece - .010" - 6 hours outgassed	37
1 Piece - .010" - 48 hours outgassed	38
1 Piece - .020" - 48 hours outgassed	39
3 Pieces - .010" - 6 hours outgassed	40
3 Pieces - .020" - 6 hours outgassed	41
3 Pieces - .020" - 48 hours outgassed	42

A review of Tables 37 through 42 will show the method used to reduce the data to a form that can provide an indication of the probable total outgassing in the switch. Column 4 of the tables was obtained from the basic corrected data, and is the total gas evolved per minute from the gas collecting test. Column 1 shows the temperature spread for the same period, with conversion to ^{o}K, while Column 2 lists the <u>average</u> temperature over the 1 minute period. The third column is obtained from 2, and the values are in a form to simplify the resulting graph.

Column 5 is obtained from 4 by dividing by 60 and the total surface area of the samples. The samples are 1 cm by 4 cm with thickness of 0.010" and 0.020" (or thickness of 0.254 mm and 0.508 mm). Thus, total area for the three thicknesses being considered is as follows:

THICKNESS	AREA - SQ. CM.
.010"	10.54
.020"	13.08

The data from Tables 37 through 42 are plotted on a new curve sheet, Figure 18, which shows the hydrogen gas evolved from the various samples on a square centimeter basis, versus the temperature (using the expression $^{1}/T_{average}$).

The gas measuring system was not able to give accurate measurements of gas volume evolved at the normal operating temperatures. However, after studying the data obtainable, and the known facts about the evolution of gas as related to time and pressure, it was concluded that an extrapolation to lower temperatures from the higher temperature data could be made to obtain an estimate of the gas that would evolve. Thus the envelope curve of Figure 18 indicates the range that can be expected at the switch operating temperatures. The expected temperature for the majority of the switch metal surfaces has been selected as $600^{o}C$ ($1112^{o}F$) or $873^{o}K$.

The $^1/T_{av.} \times 10^3$ value is 1.15. This shows from the curve a possible range of gas evolution from the Rodar of 4×10^{-7} to 3.5×10^{-6} micron liters/second.

The surfacesin the switch exposed to the sealed section includes the end pieces, the shield (which may be made of Molybdenum) and the multiple surfaced bellows. Based on present switch designs and dimensions, it is estimated the total surface that will be evolving gas will be approximately 400 square centimeters. Further reference to Figure 18 will indicate the range of gas evolved from the total switch (400 cm^2) and the capacity of a 0.5 liter per second pump.

The conclusion from this data is that if well outgassed Rodar is used for the vacuum sealed switch, a 0.5 liter per second pump will probably handle the gas evolved and maintain the pressure near 10^{-6} Torr. On the other hand, if the pump is unable to hold the 10^{-6} pressure, the capacity will be sufficient to hold a pressure below 10^{-5} Torr which is still considered adequate for the interrupting requirements of the vacuum interrupter. Therefore, it has been decided to use Rodar for the switch metal enclosure parts, and design work is proceeding on this basis.

B. Contact Material

The Phase I Program investigation determined that contacts in the interrupter unit should be made of Molybdenum. Satisfactory interruption test results further indicated the size and shape of the contacts.

With the material and dimensions established, work during this second quarter of the program has been directed toward completion of the theoretical study of the contact behavior and parameters, under the 1000°F environment temperature and in view of the continuous and momentary currents which the contacts must handle. Additional test data is also being obtained on the Phase I contacts to supplement the theoretical results, and design of the contacts including processing techniques was also started.

1. Theoretical Considerations

The preliminary studies of contact resistance phenomena(1) showed a high probability of "single point" contact between hard nominally plane molybdenum contacts. The predicted levels of contact resistance (about 0.2 milliohms) were observed in real switchgear at low current level. A word of caution was inserted to the effect that testing under full current conditions might be expected to reveal substantially different contact resistance (and contact welding) characteristics because of the softening of the contact material at the constriction and the actual melting of the contact at this point under maximum current conditions.

(1) First Quarterly Report (NASA CR-54247).

The contact resistance properties were defined in terms of an average constriction temperature (which in turn defines the resistivity and mechanical properties) assuming negligible temperature rise over the base electrode near the constriction. This assumption is reasonably valid for low current operation in which the heating is relatively unimportant. It is, at best, a first estimate under high current test conditions. Holm[(2)] gives the following expression for the calculation of the supertemperature of the constriction boundary (its elevation over the base temperature of the electrode):-

$$\Delta T = \frac{U^2}{8 \rho \ k} \quad {}^{o}K$$

U volts contact drop

ρ resistivity ohm cm

k conductivity watt / cm ^{o}K

Unfortunately, the contact potential drop U is a function of the supertemperature, through its effect on ρ , and far more critically through its effect on the contact diameter 2a as a result of the softening of the contact material, at the constriction, under high current flow. It will be recalled that the radius of the contact point a was defined by:-

$$a = \sqrt{\frac{P}{\pi \ n \ H}} \quad cm$$

P contact load KG

H "Hardness" yield stress KG/cm^2

n number of equal contact points

where n=1 for all practical purposes in the molybdenum contact system. The hardness of the molybdenum contacts falls sharply as temperature rises to 500^{o}K and then much more slowly until the softening point is approached at about 1300^{o}K. The contact resistance was then shown to be R = ρ /2a, leading to a contact voltage drop of:-

(2) R. Holm, "Electric Contacts". Book, Hugo Gebers Forlag, Stockholm, 1946.

$$U = \frac{\bar{\rho} I}{2} \sqrt{\frac{\pi H}{n P}}$$ volts where $\bar{\rho}$ is average resistivity in the constriction.

We can now solve for the supertemperature in terms of the mean values of resistivity and thermal conductivity $\bar{\rho}$ and $\bar{k}$, which, in turn may be shown to be equal to their value at a temperature 2/3 of the way up from the base temperature toward the supertemperature ($T_o + 2/3 \Delta T$) For the probable case of essentially single point contact, n = 1:-

$$\Delta T = \frac{\pi H}{32 P} \frac{\bar{\rho}}{\bar{k}} I^2$$

I current thru contact amperes
$\bar{k}$ mean thermal conductivity

In the use of this expression, the value of H is rather hard to define. It is necessary to consider the effect of varying hardness (with temperature through the constriction) on the interpenetration of the asperities which constitute the contact region. Since half of the total temperature rise occurs within a distance of less than the radius of the "spot" from the contact plane, the assumption has been made that hardness <u>at the supertemperature maximum</u> may be used to define the contact radius. This will lead to a slightly optimistic (low) contact resistance with an implied increase welding probability. If we take the Wiedeman-Franz law, $\rho k = A T$, into account, the expression may be modified to eliminate the large variations in ρ over the temperature range, and lead to the approximation, assuming $A = (2.6)10^{-8}$ and $k = 1.05$ w/cm ^oK, using A and k as constants in the 1,000 to 1,500 ^oK range:-

$$\Delta T = \frac{\pi H_{eff}}{32 P} \frac{A}{k^2} (T_e + 2/3 \Delta T) I^2$$ (T_e electrode temperature ^oK)

This equation may best be applied in a series of iterative steps, first calculating <u>ΔT</u> using the value of H_{eff} for an assumed value of $T + \Delta T$ and then correcting this value, as needed, to bring about a balance. In general, as long as the supertemperature is not enough to drive the constriction barrier temperature above the softening point, the value of ΔT will be a function of I^2. If the contact temperature does exceed this limit, however, the sharp reduction in contact resistance, as the asperities settle into contact, will lead to much lower values of ΔT, not very far above the softening point. Of course, if I^2 continues to increase, contact melting, and catastrophic destruction of the electrodes may result. Solving the equation for ΔT in terms of the parameter, $K = \pi H_{eff} A I^2 / 32 P k^2$ and T_e, the electrode base temperature, we obtain:-

$$\Delta T = \frac{K}{1 + 2/3 K} T_e$$

In the region below the softening temperature, $H = (1.3)10^4$ KG/cm^2 is a reasonable approximation, and, for 50 # = 22.5 KG, the expression for K reduces to:- $K = (2.6)10^{-6} I^2$. This simplification is realistic, as long as K is fractional. At large values of this parameter, the variation in H and A/k^2 must be considered, as seen in Figure 19 . If we consider that the constriction temperature is, indeed, the proper level on which to base the indentation hardness, the value of K may be scaled from the parameter $H A / k^2$ plotted in Figure 19. Thus, at 1500°K, it will be about $(4.9)10^{-7}$ or about 19% of its low temperature value.

The temperature of the boundary plane in the constriction is given in Figure 20 as a function of the current carried by the contacts and the base temperature established at the electrodes. It will be seen that the supertemperature (increase over the base temperature) follows the quadratic law in the lower temperature region. As the constriction temperature reaches the softening region, the slope of the temperature vs. current curve decreases sharply. The supertemperature was calculated for a 1500°K constriction temperature to provide the approximation of the curve shown in this region. It may be seen that the electrode base temperature would have to be maintained at very nearly the 1000°F (811°K) ambient for the passage of 600 A not to yield an excursion into the softening region. It is very probable, therefore, that the Switchgear will always run into the softening region under overload conditions, and generally under normal current. The potential wedling hazard must be considered, but the lowered contact resistance associated with the softened contacts will substantially reduce the heat load on the nominal hard metal of the radiator system. The contact resistance will be somewhat less than that shown in Figure 8 of the first quarterly report, if the temperature defined in Figure 20 is used to estimate the resistance. Thus, if the electrode temperature is 1100°K and the current is 1000 A a supertemperature of 400°K will lead to a constriction temperature of 1500°K, with a contact resistance slightly in excess of 0.3 milliohms.

1. <u>Test, Evaluation, and Design</u>

The calculated resistance of the contact interface of molybdenum contacts at room temperature was of the order of 0.3 milliohms. This was considerably lower than the measurements made on the molybdenum contacts in the evacuated materials test capsule. Therefore the materials test capsule was opened to investigate the cause of the high contact resistance reported in the first quarterly report.

The surfaces of the contacts were rough and frosty white due to the arc tracks of the low power level interruptions. One area approximately 1/8" in diameter was extremely rough and showed evidence of molten material splattered over the area. Under a microscope the surface resembled pictures of the surface of the moon.

Three insulated guides were used to support the upper contact in alignment with the lower contact for resistance measurements. The orientation of the contacts was the same as it was during the interruption tests with the rough spots in contact. The resistance values shown in Figure 21 were measured by the voltage drop method, with a current of 10 amperes DC flowing in the electrodes and contacts. The contact force was 26 pounds, 6 ounces.

The resistance measured across the contact interface (from 5 to 6, Figure 21) was 0.3 milliohms at room temperature. This compares to the values measured on the Pittsfield vacuum switches with molybdenum contacts, and to calculations made by R. N. Edwards and reported in the theoretical discussion in the First Quarterly Report.

A further investigation of the effects of high temperature on the contact resistance is planned to supplement the theoretical information that has been developed, prior to manufacture of the first interrupter unit. The materials test capsule used in phase I will be reassembled in the oven and evacuated. A contact force of 50 lbs will be provided by a spring. Means will be attached to measure the contact temperature and the voltage drop across the contact interface.

This will provide data to check the theoretical predictions, and indicate any further problem areas.

It was previously planned that only zone refined molybdenum would be used for the contacts. It was considered that the pure metal would give the minimum of outgassing and the lowest contact resistance, although such material involves definite problems in grain orientation for best performance. It has since been decided that high purity arc cast molybdenum should be satisfactory for the contacts, provided the machined contacts are properly vacuum processed. This is based on the results of the test with the molybdenum contacts in the materials test capsule, and on the experience and background information which Dr. T. H. Lee of the General Electric Laboratory Operation has contributed to the program. The contact material will be vacuum processed at 1800°C in a vacuum of the order of 10^{-6} Torr for a period of one hour. It has been Dr. Lee's experience that the danger of extreme crystal growth will not take place with this processing.

C. Interrupter Design

The vacuum interrupter has received major attention during this report period, in order to produce a sealed unit that will satisfactorily meet all electrical and mechanical requirements. Transfer of the heat generated at the contact interface has been a major problem. Material selection and environment conditions have required special attention in developing a suitable mechanical arrangement.

At the end of the period, the interrupter unit design was rapidly being firmed up, with a concept which will be described below and which looks to be feasible and suitable for the Program requirements.

1. Heat Transfer

Several conceptual designs for the vacuum interrupter have been made since the First Quarterly Report, in an effort to remove the heat generated at the contacts. Designs previous to the Program review on April 6 conducted heat from the contacts to the bus bar connections. A maximum bus bar temperature was established by the NASA Technical Manager and the original NASA philosophy that the bus bars should neither remove nor add heat to the switch is now the design parameter. The radiation system of the first vacuum interrupter design to meet the design philosophy is shown in Figure 22 . In this design the major portion of the heat is removed by radiation to an enclosing shell which is isolated from the electrical circuit and attached to the heat sink bulkhead.

The calculated temperatures of various points in the radiator system are shown on the sketch in Figure 22 . These temperature calculations indicated the areas in which design changes could be made to reduce the temperature of the contacts. The coefficient of thermal conduction through the bolted joint between the bulkhead and the mounting flange of the circuit breaker was extremely conservative. In practice this coefficient could be 10 to 1 higher than the value used. This would reduce the temperature of both contacts. Other changes that would help reduce the contact temperature are:

a) The elimination of the bolted joint between the fixed contact base and the lower radiating structure.

b) Increasing the cross sectional area of the thermal path between the contacts and the radiators.

c) Decreasing the electrical resistance of the contact electrodes.

A simplified radiator system has now been devised that will cost less to fabricate. In this arrangement all of the fins radiate to the outside shell directly and do not overlap. The design shown in Figure 23 includes the refinements tabulated above.

The cooling system will not be required on the DC engine contactor because the heat generated at the contacts will be negligible. Thus the simpler concept shown in Figure 24 is a definite possibility.

2. Mechanical Arrangement

The design of a single interrupter for both the AC breaker and DC contactor would require high heat radiation for the AC breaker and high insulation for the DC switch. In short, the design would be a 600 ampere 10,000 volt device. To confine the high heat dissipation to one design and the high insulation to another would reduce the overall cost. This can be done by having a single vacuum interrupter unit or capsule that would be common to both the Breaker and Contactor.

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The design concept now being considered uses the alumina-rodar shell and bellows to make up the vacuum enclosure. In the enclosure will be the molybdenum contacts and shield to prevent contamination of the alumina insulation. Either the radiation fins required for the AC breaker or the electrical connections for the DC contactor would be added to the completed vacuum capsule. The radiation fins would be attached by a temperature shrink process to provide good thermal path as shown in Figure 23 . The DC switch connections would be bolted to the vacuum capsule as shown in Figure 24 . Design work is now being concentrated on providing this combination arrangement.

3. Ion Pump

The results of the materials outgassing test indicated a continuous pumping means with a speed of 0.5 liter/sec. will be needed to maintain a 10^{-6} Torr vacuum at the high temperature. The 0.5 liter/sec. pump manufactured by the General Electric Vacuum Products Operation is the smaller of the units available from three manufactures in this business. The pumps of this size manufactured by both Consolidated and Ultex are larger and their unsymmetrical arrangement about the pump unit axis, would cause arrangement problems.

The pump must withstand the mechanical loads imposed by the shock and vibration requirements. Therefore, a General Electric Vacuum Products pump has been obtained, mounted on a suitable fixture (shown in Figure 25) and vibration tested. There were no indications of mechanical failure. Details of the test are given in Appendix A. The pump will be tested to check its pumping characteristics early in the next work period to confirm its suitability for this program.

A review of the pump characteristics shows that to obtain the rated capacity, temperature must be held to a maximum of approximately 200°C. For the present prototype, this can be done using a sealed enclosure around the pump and circulating cooling air through it. Flight type units would require redesign of this accessory.

IV MECHANISM

The vacuum interrupter switch is moved by a mechanism, or actuator. This part of the Breaker or Contactor is mounted above the switch and on the same centerline. Movement is obtained with a solenoid which moves approximately 3/8" to impart a 1/4" travel to the switch contacts plus a 1/8" compression of a "wipe" or contact pressure spring.

This report will discuss the work that has been done on the overall mechanism during the last three months. Detail work on the development of the solenoid guide diaphrams, the mechanism linkage, latch and trip device, and the main operating solenoid will also be reviewed.

A. Mechanism Arrangement

A variety of actuator arrangements have been considered including the long toggle linkage, the rotary latch linkage, and the reverse toggle linkage.

At the April 23 Design Review Meeting the conceptual design of the long linkage actuator proposed at the close of Phase I was re-examined for fabrication cost, dynamic instability, ability to survive the mechanical test, and over-all length. Mr. Levy, Senior Mechanical Engineer in ATL stated that in his opinion, the actuator would survive the mechanical test, the design was not expensive to fabricate and that in the locked launch position was dynamically stable. However, the long length was an objectionable point from an application point of view.

It was decided that this design would be utilized as a back-up for any future design, and other arrangements considered.

The operation of a "rotary latch" design was considered too complex from a control point of view to be acceptable. However, a "reverse toggle actuator" was shorter in length, lighter in weight, and used only one flexural which should result in lower cost and appeared promising. A "mock-up" of the reverse toggle actuator was built, and is shown in Figure 26. The metal block at the base of the actuator is representative of the closing solenoid. The long handle is essential only to operation of the mock-up and substitutes for the force of the solenoid to close the AC breaker. Figure 27 is a double exposure photograph showing the actuator in the closed and open positions. In the closed position the vacuum interrupter contacts are held closed by the long flat tension links on each side of the closing solenoid. The arm of the linkage is further biased over center by a magnetic latch.

To open the interrupter contacts, the top of the actuator is pushed away from the permanent magnet latch, over the center of the flexural, allowing the solenoid plunger to release the movable contact to the open position. The linkage is held in the open position by the long tension links on each side.

A detailed layout drawing 587E474 of the reverse toggle actuator has been completed and issued. The section of the layout showing the mechanism in side view is shown in Figure 28. Detail drawings of the actuator components that are firmed up, are now being made.

B. Components, Designs and Tests

1. Diaphragms

The diaphragms used to center the closing solenoid armature and permit the 3/8" axial movement of the armature constitute the remaining major problem in the design of the actuator. Diaphragms made of stainless steel have not passed the vibration test. Figure 29 shows a diaphragm in the vibration test fixture. The test fixture is a mock-up of the closing solenoid with the diaphragms held in the closed position by a spring force of 50 lbs. The weight of the armature, actuator and switch parts are simulated by masses that produce the same moments of force. Two diaphragms are tested at the same time.

The test fixture in Figure 30 is attached to the vibration mounting plate in the position to apply the vibration excitation radially to the diaphragm. In Figure 31 the fixture is positioned for axial vibration excitation. Two diaphragms each 0.007" thick, have been tested and the results are given in the test data sheets, Appendix B. While they passed the scan test, they failed during one of the resonant frequency "dwell" tests.

The future plans include:

- Procurement of material with a high endurance stress characteristic, such as # 4140 or # 4340 steel.

- Redesign the diaphragms to distribute the flexural stresses.
- Make new diaphragms and test.
- Investigate convolution bellows.

2. Linkage

The long flat links on each side of the actuator linkage in Figure 32 are in tension against the contact force of 50 lbs in the closed position. The thickness and width of these strips were calculated to give the best balance between the bending and tensil stresses in the links. The selected thickness of 0.020" gives a bending stress of 16,000 PSI with the proposed material - Inconel-X type 750. Fatigue data on Inconel-X is not available at $1000^{\circ}F$; however at room temperature with 80,000 lbs. stress, samples tested with a complete reversed bend did not fail before 100,000 cycles. The width of one inch for the tension strip in our application results in a tensil stress of 1250 PSI. Inconel-X can withstand a tensil stress of 30,000 PSI at $1000^{\circ}F$.

3. Solenoids

The closing solenoid for the AC circuit breaker was originally calculated to supply a closing force of 75 lbs. at 1/8" stroke and 100 lbs. at 5/16" stroke. This latter was 1/16 over the required stroke to assist in latching the mechanism. The flux required to furnish this force was calculated to be 141 kilolines. In the magnetic structure shown in the early designs, this would require 3830 ampere turns. Assuming a current of 1.5 amperes and 225 turns the solenoid would take 119 watts of power. It was calculated that the temperature of the coil would increase $9^{\circ}C$ per second at $1000^{\circ}F$ for steady state operation. However, the time of operation will be of the order of 0.1 second and thus any increase in temperature can be neglected.

With the additional data and details of the bellows, diaphrams, and connection to the moving coil, new loads have been determined. It appears that a force of 100 lbs will be required at 1/8" stroke, and 125 lbs at 5/16" stroke.

To obtain this increased force, the magnetic structure has been changed, decreasing the flux density. The ampere turns and total flux, however, have not been changed.

V TEST PLANS AND FACILITIES

The complete prototype Breakers and Contactors will be subject to a wide range of Electrical and Mechanical tests, as specified in the Contract. These tests will include interruption of twice normal current, heat runs and high voltage leakage. Mechanical tests will check for performance under launch environment conditions.

Plans for the final tests are only being formulated and procedures considered. However, facilities required are being checked and reserved, and special equipment such as the oven for the heat run and endurance test is in manufacturing. Some details on this work will be covered in this section.

A. Electrical

Detail planning work for the electrical interruption tests will start during the third quarter of 1965. However, preliminary work was done during the past quarter on checking the capacitor banks available in the Schenectady plant of General Electric where the tests will be made. Circuit parameter data was also obtained to aid in planning the tuned circuit and related connections and switching devices. There was some question that the capacitors in the bank could be reverse charged in the 2000 cps "ringing" circuit. This point has been resolved and the bank can be operated up to 2000 volts peak, without damage by reversal. Thus, adequate capacity is available to provide the electrical limits of 1200 amperes at 1000 volts and with a 2000 cycle per second frequency.

Length of time the circuit is closed and speed of switch operation are important considerations in determining if a low enough circuit decay rate can be maintained. Some indication of the problem is shown in the following tabulation with the proposed equipment:

% Reduction of Peak E & I	50	50	25/27	* 25/27	25/27	10
System Q (Indication of Merit)	100	200	100	200	500	200
Brkr. Closed Time-Milli-Seconds	10	22	4.5	9	25	3.2

*This column indicates a feasible condition.

An alternate approach to the decrement problem would be to supply 2000 cps power, equal to the decrement power, from a fixed power source. The fixed source would be connected to the circuit after the circuit breaker under test is closed. This method of test would require a means of phasing the tuned current and the power source current. It is under further investigation.

B. Mechanical

The Breaker and Contactor are being developed to meet mechanical test conditions involving vibration over a range of 20-2000 cps, shock at 35"g", acceleration at 7"g" and acoustical with noise levels of 148 db and frequency range of 20-2000 cps.

Both the shock and vibration will be performed at the Schenectady plant of the General Electric Company. The facilities have been checked for availability. Fixtures for mounting the switchgear will be developed during the next quarterly period. However, component testing on the vibration machine is already underway, as reported in the sections of this report on the ion pump and mechanical diaphrams.

C. Heat Run and Endurance

The basic new facility that will be required for the Heat Run, Electrical Leakage, and Long Time Endurance Tests, is an oven which will mount inside a vacuum tank such as shown in Figure 2 and provide the $1000^{\circ}F$ environment in a pressure of 10^{-6} Torr. The basic design of the oven was described in the First Quarterly Report. During this quarter, all oven material was ordered and much of it was received. The oven is being fabricated from Rodar. The heating elements are long quartz tubes with tungsten filaments. Alumina insulators support the lamps around the sides and in the top and bottom supports.

The lamp control circuitry was developed during this quarter, and needed vacuum tank feed throughs for the required power circuits are under consideration. Thermocouple connecting means, and arrangements for recording the data are also being studied.

Test procedures for both heat run and high voltage leakage testing have been started and will be available during the third quarter. One of the major problems revolves around the need for making all the tests and circuit checks required for both the heat run and leakage tests, without opening the vacuum chamber.

APPENDIX A

VIBRATION TEST ON ION PUMP

I. EQUIPMENT

The vibration equipment is a model 91A Unholtz-Dieky vibration system consisting of a vibration head and a control console complete with frequency and amplitude controls. The resonance frequencies were double checked on a Berkley E-put meter.

Resonances are determined by either the output waveshape of a vibration pick-up, by visual observation, or audible sound.

II. TEST SPECIFICATIONS

Scan the frequency range in 1 to 10 minutes with logarithmic sweep on each of three major axis at the inputs tabulated below. At each major resonance frequency, sine wave excitation will be applied for 5 minutes at the levels specified below:

Frequency	Scan Level	Resonance Level
16 - 100 cps	6 "g"	3 "g"
100 - 180 cps	0.118: P/P	0.0059" P/P
180 - 2000 cps	19 "g"	9.5 "g"

III DEVICE OR ITEM

Ion pump. General Electric Vacuum Products Operation, Model 22TP050 #4004 0.5 liter/sec. Magnet removed.

IV. MAJOR AXIS OF VIBRATION EXCITATION

Magnet removed from the pump unit.

Axis - 1 Along the major axis of the pump unit.

Axis - 2 Along the diameter of the pump body, radial to major axis of the pump unit.

Axis - 3 None

V. TEST RESULTS

A. Scan Completed In:

	Axis-1	Axis-2	Axis-3
Minutes	9	9	9

B. Major Resonance Frequencies (cps)

Axis-1	Axis-2	Axis-3
None	240	
	700	

C. Five Minute Dwell at Above Frequencies

Dwell completed at	240
	700

No indication of mechanical damage.

Test of pumping characteristics not completed.

APPENDIX B

VIBRATION TEST ON MECHANISM DIAPHRAMS

I. EQUIPMENT

The vibration equipment is a model 91A Unholtz-Dieky vibration system consisting of a vibration head and a control console complete with frequency and amplitude controls. The resonance frequencies were double checked on a Berkley E-put meter.

Resonances are determined by either the output waveshape of a vibration pick-up, by visual observation, or audible sound.

II. TEST SPECIFICATIONS

Scan the frequency range in 1 to 10 minutes with logarithmic sweep on each of three major axis at the inputs tabulated below. At each major resonance frequency, sine wave excitation will be applied for 5 minutes at the levels specified below:

Frequency	Scan Level	Resonance Level
16 - 100 cps	6 "g"	3 "g"
100 - 180 cps	0.118: P/P	0.0059" P/P
180 - 2000 cps	19 "g"	9.5 "g"

III DEVICE OR ITEM

Actuator diaphragms 0.007" thick made of stainless steel shim stock. Two diaphragms in mock-up of solenoid in solenoid closed position and loaded by a spring force of 50 lbs. The weight of solenoid armature, actuator and applicable switch parts simulated.

IV. MAJOR AXIS OF VIBRATION EXCITATION

Axis - 1 Refer to Figure 29.

Axis - 2 At 45^{o} Mounting of Figure 30.

Axis - 3 Vertical Position - Refer to Figure 31.

V. TEST RESULTS

A. Scan Completed In:

	Axis-1	Axis-2	Axis-3
Minutes	9	9	9

B. Major Resonance Frequencies (cps)

Axis-1	Axis-2	Axis-3
173	176	
224	280	
643	625	
713	700	
1190	1210	
	1650	

C. Five Minute Dwell at Above Frequencies

Completed the 5-minute dwell on all resonant frequencies in axis-1. Diaphragm ruptured after 4-minute dwell at 176 cps in axis-2.

TABLE 1

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .010" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	98					
3	169		.42	0		
4	248		1.04	0		
5	325		1.66	.07		0
6	400		2.38	.10	0	.07
7	467		3.38	.21	.05	.25
8	526	.8	4.06	.11	.00	.30
9	578	1.2	4.48	.17		.31
10	630	1.6	4.84	.19	0	.31
11	680	1.6	5.14	.16	0	.32
12	722	1.8	5.4	.13	0	.30
13	765	1.8	5.71	.00	0	.29
14	797	2.0	5.93	0	0	.25
15	797	2.0	6.15	0	0	.24
16	794	2.2	6.31	0	0	.21
17	793	2.2	6.53	0	0	.18
18	794	2.3	6.71	0	0	.15

TABLE 2

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .020" Thick x 1 cm x 4 cm

As Recieved, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	61					
2	106		0	.08		
3	178		0	.09		
4	265		0	.10		
5	347		0	.11		
6	425		0	.09	0	0
7	495		0	.21	0	0
8	555	1.0	0	.35	.20	.38
9	612	9.0	0	.45	.20	.44
10	660	17.0	0	.37	.15	.50
11	712	19.7	0	.44	.15	.52
12	743	19.9	0	.48	.15	.52
13	784	20.3	0	.60	.10	.53
14	806	20.3	0	.78	.10	.53
15	798	20.5	0	.93	.10	.50
16	793	20.5	0	1.06	0	.48
17	790	20.6	0	1.25	0	.48
18	788	20.5	0	1.31	0	.44

TABLE 3

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .060" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	53					
2	100		.73			
3	178		1.54	.13		
4	265		2.31	.19		
5	350		2.96	.23		
6	425		3.85	.27		0
7	495		4.65	.35	0	.07
8	553	.40	5.60	.45	0	.14
9	605	.20	6.88	.57	0	.31
10	655	2.80	8.55	.85	0	.53
11	700	13.00	9.24	.96	0	.63
12	746	36.40	9.60	.96	0	.72
13	788	66.20	10.07	.93	0	.76
14	808	93.60	10.60	.89	0	.74
15	802	108.40	10.96	.90	0	.77
16	799	115.30	11.16	.93	0	.74
17	797	117.10	11.48	1.03	0	.72
18	797	117.00	11.86	1.11	0	.72

TABLE 4

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired at 1550°F for 6 Hours at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	59					
2	95		0			
3	170		0			
4	250		0	0		0
5	325		0	0		.03
6	400		0	0		.07
7	466		0	0	.10	.22
8	524		0	0	.20	.42
9	577		0	0	.25	.53
10	627		0	0	.35	.70
11	672		0	0	.40	.78
12	714	.10	0	.12	.45	.83
13	756	.20	0	.30	.50	.81
14	793	.30	0	.46	.50	.83
15	830	.60	0	.57	.65	.87
16	865	1.00	0	.55	.70	.86
17	897	1.30	0	.57	.80	.87
18	910	1.90	0	.72	.90	.89
19	905	2.70	0	.86	1.05	.90
20	904	3.60	0	1.00	1.25	.90

TABLE 5

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at $1550^{o}F$ at 10^{-8} Torr

Time Min.	Temp. ^{o}C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	55					
2	101		.00	0		
3	172		0	0		
4	259		0	0		.00
5	340		0	0	0	.07
6	415		0	0	0	.09
7	480		0	0	.10	.15
8	538		0	0	.10	.21
9	593	.10	0	0	.15	.27
10	646	.20	0	0	.15	.33
11	695	.10	0	0	.15	.37
12	740	.10	0	.00	.15	.41
13	780	.10	0	.08	.15	.37
14	820	.30	0	.20	.15	.37
15	855	.50	0	.10	.05	.28
16	884	.80	0	.00	.05	.40
17	909	1.40	0	0	0	.39
18	907	2.20	0	0	0	.39
19	906	2.90	0	.00	0	.39
20	902	3.90	0	.10	0	.39

TABLE 6

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	47					
2	87		0	0		
3	153		0	0		0
4	237		0	0		.00
5	320		0	0	0	.07
6	398		0	0	0	.12
7	468	.10	0	0	.10	.22
8	533	.20	0	0	.15	.28
9	602	.20	0	0	.20	.44
10	645	.20	0	.08	.35	.70
11	697	.20	0	.16	.40	.99
12	742	.20	0	.22	.45	1.03
13	787	.20	0	.37	.50	1.14
14	828	.40	0	.49	.55	1.16
15	869	.80	0	.64	.55	1.15
16	906	1.20	0	.64	.60	1.21
17	913	2.10	0	.70	.70	1.18
18	910	3.50	0	.89	.70	1.18
19	910	4.90	0	.99	.80	1.18
20	910	6.00	0	1.15	.90	1.19

TABLE 7

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	57					
2	98		0	.00		
3	171		0	.00		0
4	250		0	.00		.00
5	325		0	.00		.07
6	402		0	.03	0	.09
7	466		0	.05	.05	.19
8	525		0	.06	.10	.26
9	579		0	.10	.10	.28
10	627		0	.13	.15	.35
11	674		0	.23	.20	.37
12	716	0	0	.25	.15	.39
13	759	0	0	.30	.15	.37
14	786	.10	0	.40	.15	.39
15	833	.50	0	.49	.15	.38
16	867	1.00	0	.29	.10	.39
17	900	1.50	0	.09	.05	.39
18	908	2.40	0	.16	0	.37
19	904	3.30	0	.28	.05	.37
20	904	4.20	0	.80	.15	.37

TABLE 8

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours in 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	53					
2	87					
3	171		0	0		
4	240		0	0		0
5	320		0	0		.00
6	405		0	0	0	.05
7	477		0	0	.05	.11
8	490		0	0	.10	.18
9	600		0	0	.10	.24
10	654		0	0	0	0
11	703		0	.00	.10	.32
12	751	.00	0	.09	.15	.31
13	795	.05	0	.20	.15	.33
14	838	.20	0	.22	.15	.33
15	878	.50	0	.34	.15	.32
16	910	.70	0	.26	.20	.33
17	915	1.30	0	.25	.20	.33
18	915	2.00	0	.25	.20	.31
19	915	2.70	0	.25	.25	.31
20	915	3.20	0	.32	.25	.31

TABLE 9

GAS ANALYSIS SUMMARY

Rodar - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	65					
2	108		0	0		
3	178		0	0		
4	259		0	0		
5	334		0	0		.00
6	410		0	0		.00
7	475		0	0	0	.08
8	534		0	0	0	.11
9	588		0	0	.05	.14
10	636		0	0	.15	.25
11	685		0	0	.20	.32
12	727	0	0	0	.20	.39
13	768	0	0	0	.20	.44
14	808	.10	0	.00	.20	.42
15	844	.20	0	.10	.05	.45
16	881	.50	0	0	.10	.44
17	912	.90	0	0	.10	.44
18	914	2.00	0	0	.05	.42
19	912	3.50	0	0	.05	.42
20	910	4.60	0	.10	.10	.42

TABLE 10

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .010" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. ^{o}C	MICRON LITERS TOTAL				
		H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	56					
2	105			.14		
3	184		.17	.16		
4	270		.35	.24		
5	352		.66	.20		
6	430	.10	1.08	.24		.22
7	497	1.2	2.50	1.44	.35	1.23
8	556	4.4	3.07	2.42	.45	1.66
9	617	6.6	2.92	3.58	.40	1.75
10	660	8.6	2.50	4.97	.25	1.82
11	707	10.2	2.16	6.29	.20	1.84
12	751	11.8	1.82	7.45	.05	1.90
13	790	13.3	3.58	8.31	.00	1.89
14	810	14.6	1.47	8.89		1.91
15	801	15.8	1.29	9.85		1.93
16	797	16.9	1.19	10.35		1.92
17	795	17.7	1.11	11.00		1.90
18	795	18.0	.96	11.45		1.88

TABLE 11

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .020" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	55					
2	93		.15			
3	163		.08			
4	248		.11			
5	325		.19			
6	405		.26			
7	467	.10	.49			.18
8	528	.80	1.39	.77	.15	.80
9	583	3.40	1.50	1.63	.15	.96
10	632	6.20	.90	3.89	.15	1.09
11	680	9.80	.00	7.07	.00	1.15
12	723	13.00		9.33		1.19
13	765	15.10		11.03		1.17
14	800	16.40		12.10		1.17
15	800	17.60		12.91		1.18
16	795	18.90		13.68		1.18
17	793	19.70		14.25		1.18
18	793	20.60		14.66		1.16

TABLE 12

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .060" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	105		.23			
3	171		..60			
4	255		1.04			
5	336		1.43			
6	414		1.89	.10		
7	477		2.03	.12	.00	
8	538		2.57	.25		.07
9	593		3.38	.40		.42
10	642	2.0	4.80	1.42		.86
11	690	5.4	5.39	2.53		1.05
12	732	9.0	5.16	4.70		1.16
13	777	14.3	3.85	8.64		1.01
14	805	18.4	2.85	12.64		.86
15	800	19.5	2.17	15.65		.82
16	797	22.1	1.81	17.65		.79
17	795	23.7	1.23	19.10		.77
18	795	25.4	1.11	20.25		.75

TABLE 13

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hrs. at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	56					
2	100		0	0		
3	171		0	0		
4	251		0	0		
5	331		0	0		
6	405		0	0	.05	
7	470		0	0	.05	
8	528	.20	0	.19	.20	
9	585	2.00	0	2.29	.25	
10	635	6.40	0	4.97	.25	Not Recorded
11	683	9.50	0	7.06	.20	
12	725	11.90	0	8.66	.15	
13	766	14.10	0	9.85	.15	
14	806	16.70	0	11.72	.15	
15	842	19.00	0	13.32	.10	
16	878	21.60	0	15.10	.05	
17	902	24.10	0	17.14	0	
18	900	26.60	0	19.62	0	
19	897	28.70	0	21.70	0	
20	897	31.00	0	23.25	0	

TABLE 14

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired at 1550°F for 6 Hours at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	52					
2	100		0	0		
3	157		0	0		.07
4	237		0	0		.09
5	322		0	0		.18
6	401		0	0	0	.27
7	472		0	0	.10	.41
8	537		0	0	.20	.61
9	596		0	.23	.40	1.05
10	648	2.0	0	1.80	.45	1.25
11	701	5.10	0	4.16	.30	1.33
12	748	8.50	0	6.24	.20	1.38
13	795	11.30	0	7.98	.10	1.40
14	837	14.10	0	9.32	0	1.41
15	877	16.20	0	10.82	0	1.41
16	911	18.60	0	12.30	0	1.40
17	910	20.90	0	13.94	0	1.40
18	906	23.20	0	15.62	0	1.38
19	905	25.10	0	16.90	0	1.36
20	903	26.40	0	17.75	0	1.34

TABLE 15

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	55					
2	94		0			
3	163		0	0		.04
4	242		0	0		.11
5	327		0	0		.18
6	405		0	0	0	.24
7	480		0	.05	.05	.30
8	540		0	.06	.10	.37
9	590		0	.10	.15	.42
10	635		0	.16	.20	.31
11	680	.10	0	.26	.20	.70
12	721	.20	0	.92	.20	.95
13	765	2.50	0	2.48	.05	1.08
14	801	5.10	0	4.07	0	1.16
15	837	7.40	0	5.39	0	1.29
16	872	9.60	0	6.55	0	1.39
17	901	11.90	0	7.74	0	1.40
18	897	14.80	0	9.22	0	1.46
19	890	17.10	0	10.60	0	1.47
20	887	19.20	0	11.85	0	1.52

TABLE 16

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hrs. at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	104		0	0		
3	173		0	0		.05
4	258		0	0		.09
5	335		0	0		.18
6	405		0	0	0	.25
7	467		0	0	.05	.41
8	526		0	.03	.10	.76
9	580	1.00	0	1.46	.15	.88
10	627	2.80	0	2.88	.15	.95
11	675	4.30	0	3.84	.10	1.00
12	718	5.70	0	4.76	.05	.84
13	759	7.10	0	5.40	0	1.03
14	797	8.90	0	6.87	0	1.05
15	833	10.80	0	8.10	0	1.07
16	868	13.00	0	9.20	0	1.10
17	897	15.50	0	10.84	0	1.07
18	909	18.40	0	12.72	0	1.05
19	905	20.90	0	14.50	0	1.03
20	900	22.90	0	16.25	0	1.01

TABLE 17

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hrs. at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	102		.15	.04		
3	156		.13	.03		.05
4	242		.03	0		.11
5	325		0	0	.05	.18
6	403		0	.03	.10	.23
7	475		.04	.05	.05	.33
8	538		0	.09	.10	.46
9	597		.09	.16	.20	.75
10	649	.80	0	1.50	.20	.97
11	700	2.50	0	0	.05	1.03
12	746	3.90	0	3.42	0	1.12
13	788	5.30	0	4.27	0	1.23
14	827	6.90	0	5.17	0	1.27
15	867	8.60	0	6.07	0	1.33
16	903	10.40	0	7.00	0	1.37
17	906	12.30	0	0	0	1.41
18	905	14.20	0	8.82	0	1.46
19	903	15.70	0	10.00	0	1.47
20	903	17.40	0	10.65	0	1.49

TABLE 18

GAS ANALYSIS SUMMARY

TD Nickel - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hrs. at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	107		0	0		
3	178		0	0		.07
4	265		0	0		.11
5	348		0	0	.05	.18
6	426		0	0	.05	.20
7	495		0	0	.05	.26
8	550		0	0	.10	.35
9	602		0	0	.15	.42
10	650	.20	0	0	.20	.55
11	699	.20	0	.13	.25	.78
12	740	.40	0	.98	.30	1.05
13	780	2.90	0	2.60	.25	1.14
14	818	5.10	0	3.92	.10	1.23
15	856	7.00	0	5.06	0	1.30
16	888	9.20	0	6.10	0	1.36
17	908	11.50	0	7.27	0	1.40
18	902	14.0	0	8.02	0	1.42
19	900	16.10	0	8.90	0	1.43
20	898	18.00	0	9.75	0	1.45

TABLE 19

GAS ANALYSIS SUMMARY

Titanium - 1 pièce .010" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	60					
2	105					
3	183		.12			
4	262		.33			
5	341		.54			
6	415		.77	.16	.10	.16
7	482		.77	.28	.20	.18
8	541		.45	.38	.25	.14
9	597		.03	1.14	.20	.06
10	643		.30	1.40	.00	.00
11	694		.50	1.61	.00	.00
12	740	18.8	.75	1.84	.00	.00
13	779	27.3	1.08	2.01	.00	.00
14	813	40.0	.00	2.13	.00	.00
15	806	51.0	.00	2.25	.00	.00
16	801	50.3	.00	2.43	.00	.00
17	789	48.3	.00	.00	.00	.00
18	799	46.5	.00	.00	.00	.00

TABLE 20

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .020" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL				
		H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	65					
2	105		.15	.00		
3	172		.42	.00		
4	259		.62	.00		
5	344		1.33	.10		.11
6	421		1.78	.62	.25	.55
7	490	.10	3.15	1.27	.70	.79
8	550	1.80	2.72	1.50	1.15	.78
9	610	5.60	1.50	1.73	1.25	.59
10	660	7.20	.46	1.53	1.1	.31
11	710	9.40	.00	.98	.75	.13
12	745	15.40		.45	.45	.00
13	784	25.10		.08	.10	
14	795	36.80		.00	.00	
15	793	44.70				
16	788	44.55				
17	791	42.80				
18	794	42.30				

TABLE 21

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .060" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL				
		H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	60					
2	90					
3	159		1.20	.13		
4	242		1.77	.16		
5	327		2.50	.16		
6	410		3.28	.19		.11
7	482		4.07	.38		.35
8	548	.40	5.07	.83	.50	.62
9	607	2.30	4.70	.109	.70	.61
10	661	6.80	3.23	.119	.60	.38
11	713	9.20	2.08	.78	.25	.19
12	760	15.20	1.25	.41	.00	.06
13	803	24.70	.77	.9		.00
14	814	37.00	.40	.00		
15	811	47.40	.06			
16	807	49.80	00			
17	806	49.30				
18	806	48.40				

TABLE 22

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	104		.00	.00	.00	.00
3	173					
4	256					
5	336					
6	410	.50				
7	477	2.80				
8	534	6.20				
9	590	10.20				
10	636	5.1				
11	685	.70				
12	729	.20				
13	770	.20				
14	811	.40				
15	837	.60				
16	881	.70				
17	906	1.10				
18	903	1.20				
19	902	1.20				
20	902	1.00				

TABLE 23

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	53		.00	.00		.00
2	98					
3	171					
4	248					
5	325					
6	400					
7	466	.50			.10	
8	525	1.70			.15	
9	577	3.20			.15	
10	627	2.05			.10	
11	672	.50			.00	
12	718	.10				
13	759	.05				
14	790	.00				
15	834					
16	867					
17	901					
18	901					
19	898					
20	898					

TABLE 24

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	46					
2	84		.80	.00		.00
3	150					
4	231					.00
5	317					
6	395				.10	
7	467	.10			.05	
8	532	.70			.15	
9	588	4.40			.20	
10	646	7.20			.20	
11	696	2.50			.05	
12	745	.80			.00	
13	788	.30				
14	831	.10				
15	870	.00				
16	908					
17	915					
18	912					
19	914					
20	914					

TABLE 25

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .010" Thick x 1 cm x 4 cm

Vacuum Fired 48 Hours

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	55					
2	79		.30			
3	170		.30			
4	248		.41			.00
5	329		.46			
6	403	.20	.60	.10	.10	
7	465	3.0	.00	.14	.10	
8	523	6.4		.16	.15	
9	578	10.6		.19	.15	
10	627	11.7		.06	.15	
11	674	1.7		.00	.00	
12	716	.30				
13	757	.20				
14	795	.30				
15	830	.50				
16	866	.70				
17	900	1.00				
18	897	1.20				
19	895	1.20				
20	896	1.20				

TABLE 26

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	50					
2	88		.00			
3	153					.00
4	239			.23		
5	322			.24		
6	403			.29	.10	
7	475	1.4		.40	.20	
8	541	4.8		.43	.35	
9	600	8.4		.43	.40	
10	654	5.2		.10	.30	
11	707	1.1		.00	.15	
12	755	.30			.05	
13	800	.10			.00	
14	841	.10				
15	883	.10				
16	915	.00				
17	918					
18	918					
19	919					
20	920					

TABLE 27

GAS ANALYSIS SUMMARY

Titanium - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	64					
2	106		.00	.00		
3	181					
4	263					
5	341					
6	415					
7	478	.10			.10	.09
8	538	.70			.20	.11
9	592	3.20			.30	.00
10	640	4.90			.20	
11	688	2.20			.15	
12	730	.90			.00	
13	770	.40				
14	811	.10				
15	847	.00				
16	879					
17	899					
18	898					
19	877					
20	897					

TABLE 28

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .010" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL				
		H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	53					
2	100		.27			
3	175		.54			
4	258		.84			
5	340		1.19			
6	415		1.50			
7	485		1.84	.13		.11
8	540		2.40	.13	.10	.24
9	600		2.79	.16	.15	.31
10	650		2.98	.22	.15	.40
11	695	.2	3.21	.23	.10	.48
12	737	.4	3.32	.29	.00	.52
13	776	.8	3.39	.81		.49
14	811	2.0	3.30	1.57		.45
15	805	3.0	3.23	2.1		.44
16	798	3.9	3.19	2.4		.47
17	794	4.2	3.27	2.6		.48
18	792	4.3	3.42	2.7		.45

TABLE 29

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .020" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. ^{o}C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	94		1.27	.10		
3	159		2.46	..17		
4	242		3.74	.31		
5	327		4.96	.38		
6	407		6.11	.49	.05	.05
7	481		7.28	.58	.05	.13
8	545		8.59	.67	.10	.24
9	602	.2	9.94	.85	.20	.37
10	655	.3	10.7	.98	.30	.52
11	708	.4	11.4	1.04	.30	.63
12	755	.4	12.2	1.18	.20	.66
13	800	.5	12.8	1.55	.15	.66
14	815	1.0	13.3	2.09	.10	.69
15	811	1.2	13.8	2.38	.00	.68
16	808	1.5	14.4	2.58		.69
17	807	1.6	15.0	2.62		.70
18	807	1.6	15.5	2.74		.70

TABLE 30

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .060" Thick x 1 cm x 4 cm

As Received, Cleaned

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	65					
2	100		.54			
3	171		1.12	.07		
4	254		1.72	.10		
5	339		2.20	.10		
6	415		2.78	.14		
7	488		3.35	.19		.07
8	554	.10	3.83	.22		.12
9	610	.10	4.65	.50		.31
10	615	.20	6.55	1.23	.3	.79
11	713	.30	7.84	1.63	.65	1.04
12	752	.40	8.70	1.85	.70	1.23
13	806	1.50	9.27	2.11	.60	1.36
14	820	3.20	8.90	3.62	.40	1.44
15	813	5.20	8.66	5.03	.20	1.47
16	811	6.30	8.46	5.65	.25	1.51
17	810	6.90	8.48	6.12	.15	1.53
18	810	7.40	8.46	6.45	.15	1.58

TABLE 31

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	52					
2	90		.00	.00		
3	157					
4	238					
5	321					
6	401					
7	475					
8	538				.10	
9	597				.10	.09
10	651				.15	.14
11	704				.15	.15
12	751	.10			.15	.17
13	797	.90			.20	.15
14	839	1.30			.20	.15
15	878	1.50			.20	.17
16	910	1.60			.20	.18
17	912	1.60			.20	.19
18	912	1.80			.20	.20
19	914	2.80			.25	.20
20	920	1.80			.30	.20

TABLE 32

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	47					
2	70		.00	.00		
3	118					
4	171					
5	248					
6	325					
7	400					
8	466					
9	525					
10	581				.10	.14
11	630				.10	.19
12	677				.15	.28
13	722				.15	.28
14	763	.10			.10	.28
15	803	.10			.00	.34
16	839	.00				.35
17	874					.35
18	900					.37
19	897					.41
20	897	.10			.25	.41

TABLE 33

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL				
		H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	56					
2	94		.00			
3	159					
4	242					
5	325					
6	405					
7	477					
8	542					.09
9	597					.13
10	651			.09	.15	.22
11	702			.16	.20	.18
12	748			.19	.30	.37
13	792	.10		.24	.30	.40
14	834	.20		.46	.30	.44
15	873	.30		.77	.25	.52
16	910	.60		1.00	.20	.57
17	913	.90		1.31	.10	.61
18	912	1.30		1.82	.10	.63
19	911	1.90		2.17	.10	.63
20	914	2.00		2.55	.15	.63

TABLE 34

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .010" Thick x 1 cm x 4 cm

Vac.-Fired at 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	59		.00			
2	100					
3	171					
4	254					
5	334					
6	407					
7	472					.10
8	530				.10	.16
9	584				.15	.16
10	634				.20	.22
11	682				.15	.22
12	723				.15	.22
13	767	.10			.15	.24
14	805	.20		.20	.10	.24
15	842	.30		.26	.05	.25
16	874	.30		.26	.00	.27
17	903	.40		.27		.28
18	901	.50		.42		.28
19	897	.70		.41		.28
20	896	.70		.55		.28

TABLE 35

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .020" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	55					
2	90		.21			
3	157		..25			
4	238		.22			
5	320		.35			
6	405		.92	.08		
7	475		.73	.11		.08
8	541		.88	.13		.13
9	600		1.24	.19	.10	.16
10	653		1.45	.25	.15	.22
11	704		1.30	.29	.20	.24
12	751	Not Recorded	1.50	.33	.25	.26
13	796		1.70	.45	.25	.26
14	837		1.30	.62	.20	.28
15	877		2.20	.70	.20	.30
16	906		2.20	.80	.15	.35
17	906		2.00	.99	.10	.35
18	906		1.80	1.18	.05	.37
19	906		1.50	1.24	.00	.37
20	906	1.60	1.70	1.55	.00	.37

TABLE 36

GAS ANALYSIS SUMMARY

Molybdenum - 1 Piece .060" Thick x 1 cm x 4 cm

Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr

Time Min.	Temp. °C	MICRON LITERS TOTAL H_2	H_2O	$CO + N_2$	$C_2 - C_5$	CO_2
1	58					
2	101		.00			
3	158					
4	254					
5	329					
6	403					
7	467					.08
8	526					.09
9	578					.11
10	627					.18
11	673				.10	.39
12	717			.12	.15	.68
13	757			.30	.15	.81
14	796	.10		.71	.15	.90
15	833	.10		1.22	.00	.98
16	868	.10		1.47		1.03
17	900	.00		1.65		1.03
18	908	.10		2.04		1.03
19	906	.30		2.38		1.03
20	906	.50		2.68		1.05

TABLE 37

HYDROGEN GAS DATA SUMMARY AND REDUCTION

Rodar - 1 Piece - .010" Thick x 1 cm x 4 cm (A = 10.5 cm^2)

6 Hour Outgassed @ 1550°F and 10^{-8} Torr

Temp. Range-Over 1 Min.	T_{av} (°K)	$^1/T_{av} \times 10^3$	Total Gas Mℓ/Min.	Gas Mℓ/Sec./Cm^2
°C 714-756 °K 987-1039	1008	.993	.10	1.58×10^{-4}
°C 756-793 °K 1029-1066	1047	.956	.10	1.58×10^{-4}
°C 793-830 °K 1066-1103	1084	.912	.30	4.74×10^{-4}
°C 830-865 °K 1103-1138	1119	.887	.40	6.32×10^{-4}
°C 865-897 °K 1138-1170	1154	.865	.30	4.74×10^{-4}
°C 897-910 °K 1170-1183	1176	.851	.60	9.53×10^{-4}
°C 910-905 °K 1183-1178	1180	.847	.80	1.27×10^{-3}

TABLE 38

HYDROGEN GAS DATA SUMMARY AND REDUCTION

Rodar - 1 Piece - .010" Thick x 1 cm x 4 cm ($A = 10.5\ cm^2$)

48 Hours Outgassed @ 1550°F and 10^{-8} Torr

Temp. Range-Over 1 Min.	T_{av} (°K)	$^1/T_{av} \times 10^3$	Total Gas Mℓ/Min.	Gas Mℓ/Sec./Cm^2
°C 759-786 °K 1032-1059	1046	.957	.10	1.58×10^{-4}
°C 786-833 °K 1059-1106	1092	.915	.40	6.35×10^{-4}
°C 833-867 °K 1106-1150	1128	.887	.50	7.93×10^{-4}
°C 867-900 °K 1150-1173	1162	.860	.50	7.93×10^{-4}
°C 900-908 °K 1173-1181	1177	.850	.90	1.43×10^{-3}
°C 908-904 °K 1181-1177	1179	.848	.90	1.43×10^{-3}
°C 904 °K 1177	1177	.850	.90	1.43×10^{-3}

TABLE 39

HYDROGEN GAS DATA SUMMARY AND REDUCTION

Rodar - 1 Piece - .020" Thick x 1 cm x 4 cm ($A = 13$ cm^2)

48 Hours Outgassed @ 1550°F and 10^{-8} Torr

Temp. Range-Over 1 Min.	T_{av} (°K)	$^1/T_{av} \times 10^3$	Total Gas M ℓ/Min.	Gas M ℓ/Sec./Cm^2
°C 751-795 °K 1024-1068	1046	.958	.05	6.42×10^{-5}
°C 795-838 °K 1068-1111	1089	.919	.15	1.93×10^{-4}
°C 838-878 °K 1111-1151	1131	.885	.30	3.85×10^{-4}
°C 878-910 °K 1151-1183	1167	.858	.30	3.85×10^{-4}
°C 910-915 °K 1183-1198	1191	.840	.50	6.42×10^{-4}
°C 915 °K 1198	1198	.835	.70	8.98×10^{-4}
°C 915 °K 1198	1198	.835	.70	8.98×10^{-4}

TABLE 40

HYDROGEN GAS DATA SUMMARY AND REDUCTION

Rodar - 3 Pieces ea. - .010" Thick x 1 cm x 4 cm ($A = 31.5\ cm^2$)

6 Hours Outgassed @ 1550°F and 10^{-8} Torr

Temp. Range- Over 1 Min.	T_{av} (°K)	$^1/T_{av} \times 10^3$	Total Gas Mℓ/Min.	Gas Mℓ/Sec./Cm^2
°C 704-751 °K 977-1024	1000	1.00	.10	5.28×10^{-5}
°C 751-797 °K 1024-1070	1047	.955	.20	1.06×10^{-4}
°C 797-839 °K 1070-1112	1091	.916	.50	2.65×10^{-4}
°C 839-879 °K 1112-1152	1132	.883	1.40	7.42×10^{-4}
°C 879-915 °K 1152-1188	1170	.855	2.10	1.11×10^{-3}
°C 915-919 °K 1188-1192	1190	.840	2.20	1.16×10^{-3}
°C 919-919 °K 1192	1192	.838	2.10	1.11×10^{-3}
°C 919-919 °K 1192	1192	.838	1.90	1.01×10^{-3}

TABLE 41

HYDROGEN GAS DATA SUMMARY AND REDUCTION

Rodar - 3 Pieces ea. - .020" Thick x 1 cm x 4 cm ($A=39\ cm^2$)

6 Hours Outgassed @ 1550°F and 10^{-8} Torr

Temp. Range-Over 1 Min.	T_{av} (°K)	$^1/T_{av} \times 10^3$	Total Gas Mℓ/Min.	Gas Mℓ/Sec./Cm²
°C 587-642 °K 860-915	892	1.121	.11	4.7×10^{-5}
°C 642-693 °K 915-966	941	1.062	.11	4.7×10^{-5}
°C 693-741 °K 966-1024	990	1.010	.11	4.7×10^{-5}
°C 741-787 °K 1014-1060	1037	.965	.12	5.2×10^{-5}
°C 787-827 °K 1060-1100	1080	.926	.23	9.8×10^{-5}
°C 827-868 °K 1100-1141	1120	.874	.24	1.03×10^{-4}
°C 868-906 °K 1141-1179	1160	.863	.74	3.16×10^{-4}
°C 906-942 °K 1179-1215	1197	.835	1.13	4.83×10^{-4}
°C 942-975 °K 1215-1248	1231	.812	1.03	4.40×10^{-4}
°C 975-1003 °K 1248-1276	1262	.792	1.34	5.73×10^{-4}
°C 1003-1003 °K 1276-1276	1276	.783	1.33	5.68×10^{-4}

TABLE 42

HYDROGEN GAS DATA SUMMARY AND REDUCTION.

Rodar - 3 Pieces - .020" Thick x 1 cm x 4 cm (A = 39 cm^2)

48 Hours Outgassed @ 1550°F and 10^{-8} Torr

Temp. Range-Over 1 Min.	T_{av} (°K)	$^1/T_{av} \times 10^3$	Total Gas M ℓ/Min.	Gas M ℓ/Sec./Cm^2
°C 750-793 °K 1023-1066	1044	.957	.11	4.7×10^{-5}
°C 793-833 °K 1066-1106	1086	.922	.11	4.7×10^{-5}
°C 833-875 °K 1106-1148	1147	.872	.23	9.8×10^{-5}
°C 875-913 °K 1148-1186	1167	.858	.79	3.37×10^{-4}
°C 913-946 °K 1186-1219	1202	.831	1.56	6.67×10^{-4}
°C 946-980 °K 1219-1253	1236	.810	1.68	7.18×10^{-4}
°C 980-1000 °K 1253-1273	1263	.792	1.79	7.65×10^{-4}
°C 1000-990 °K 1273-1263	1268	.790	2.01	8.58×10^{-4}

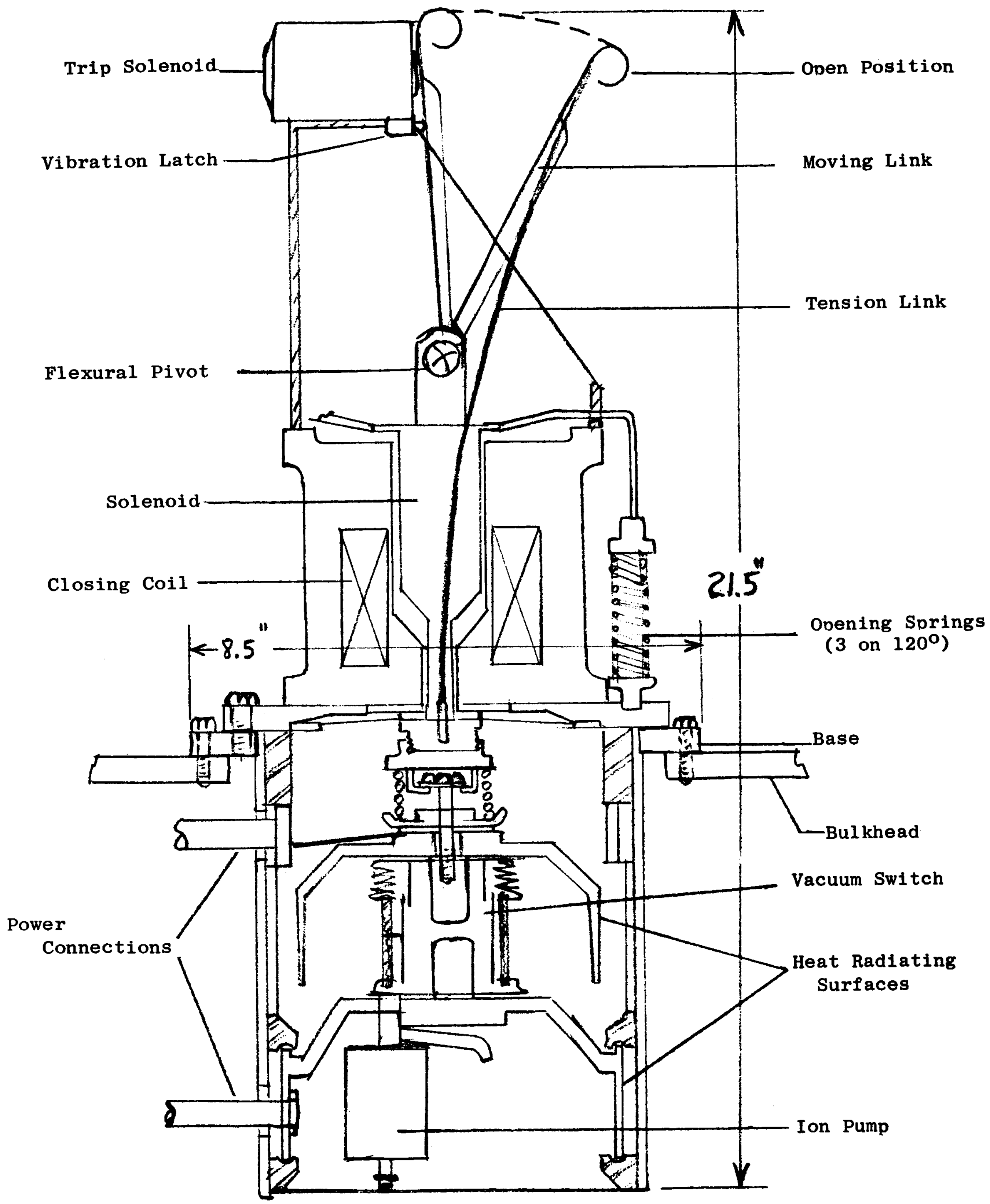


Figure 1: Conceptual Design - Vacuum Circuit Breaker.

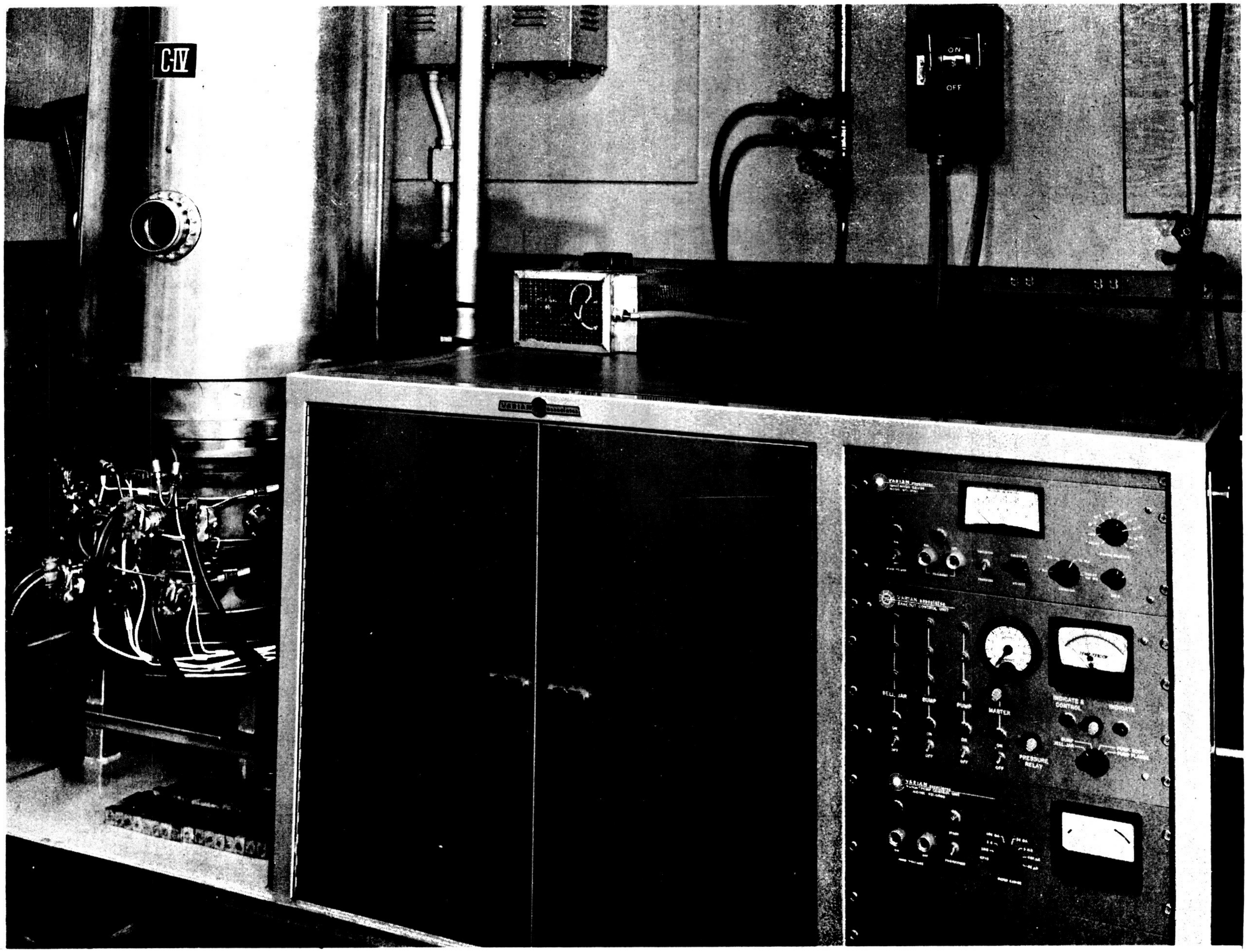
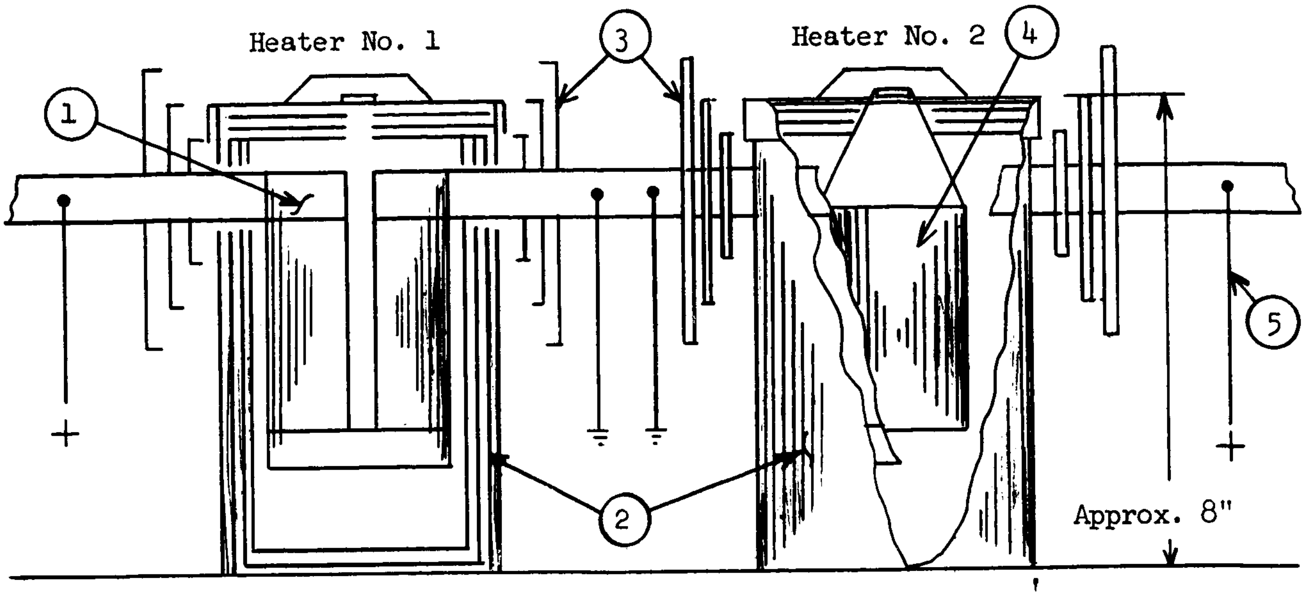
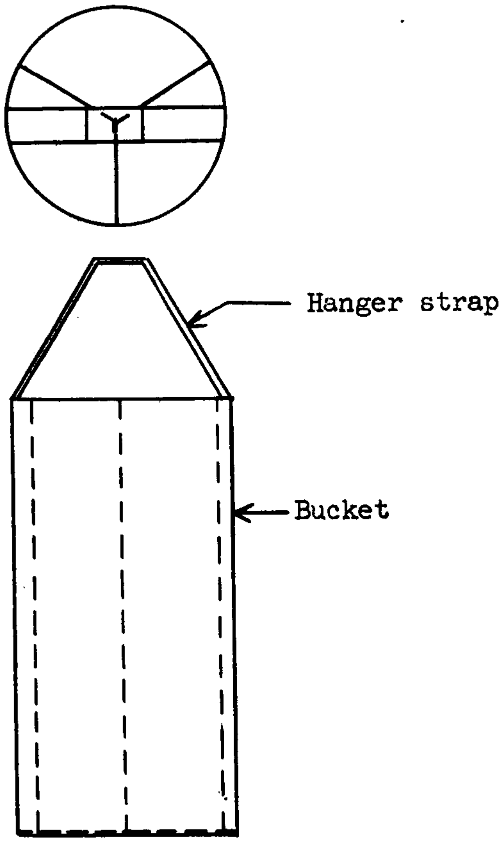


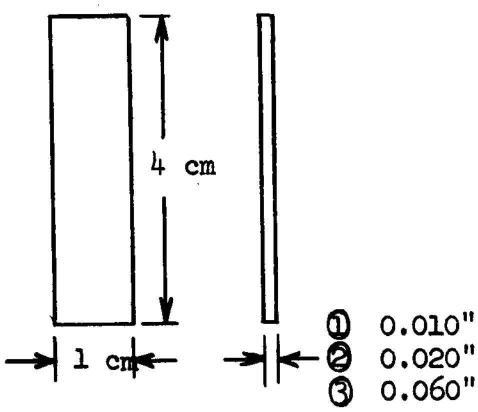
Figure 2: Ultra-High Vacuum Test Facility.



1. Tantalum heater assembly
2. Heat shield
3. Radiation shield
4. Specimen bucket (sketch below)
5. Copper bus bar



Partitioned
Specimen Bucket



Specimen

Figure 3: Small Oven and Specimen Bucket for Outgas Processing

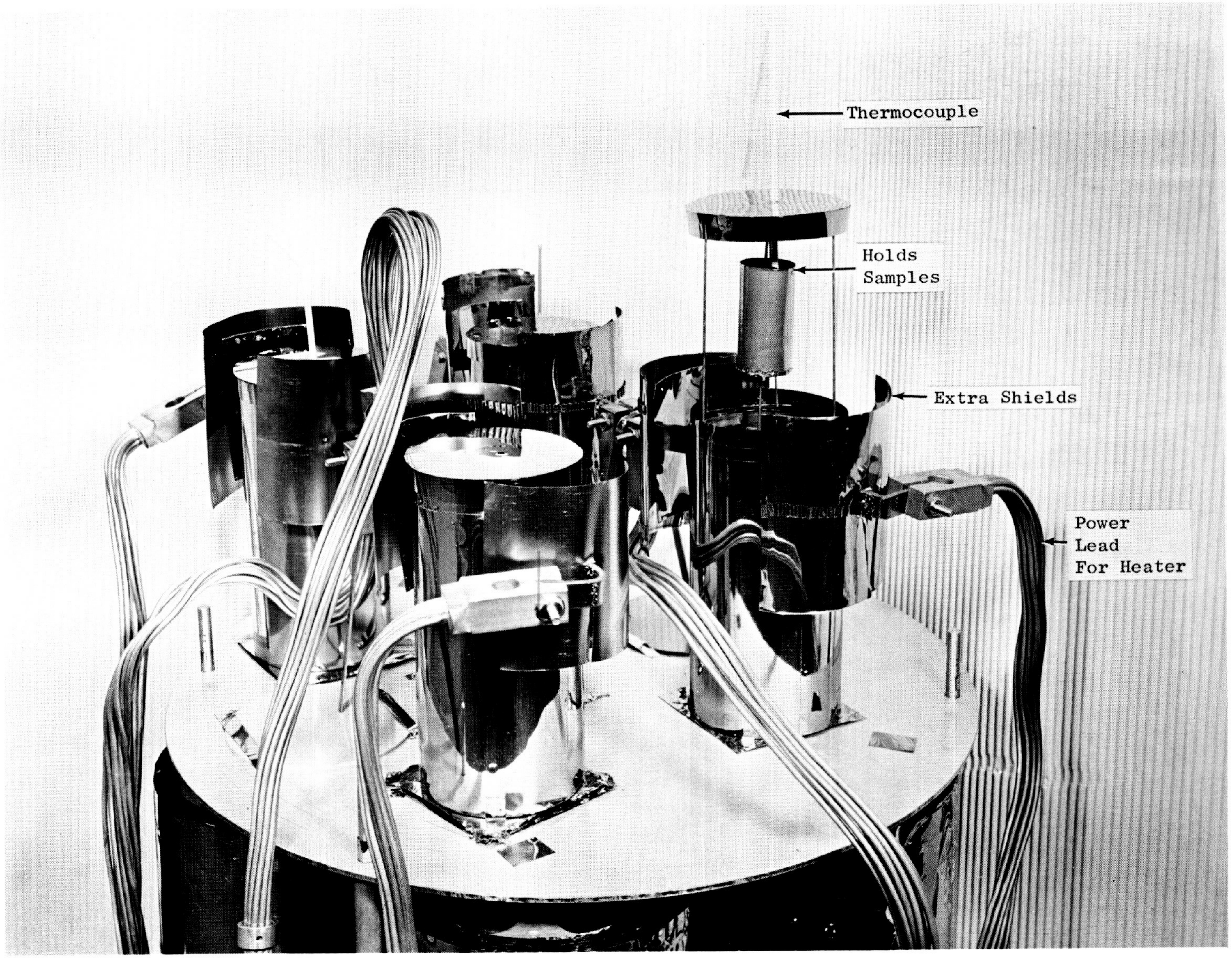


Figure 4: Heater Oven Assembly for Specimen Outgassing Tests

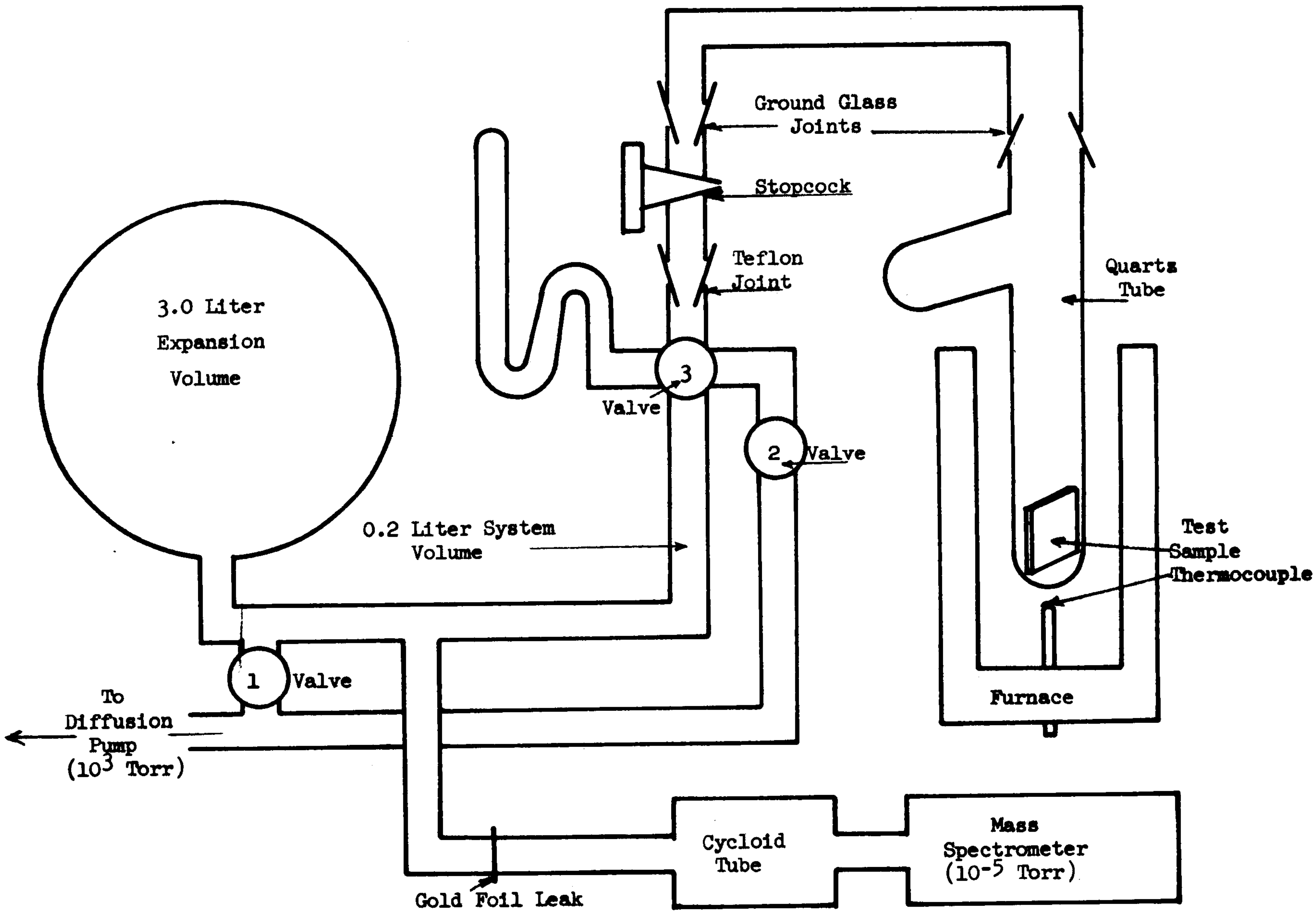


Figure 5: Mass Spectrometer Inlet System Used for Gas Collection Test.

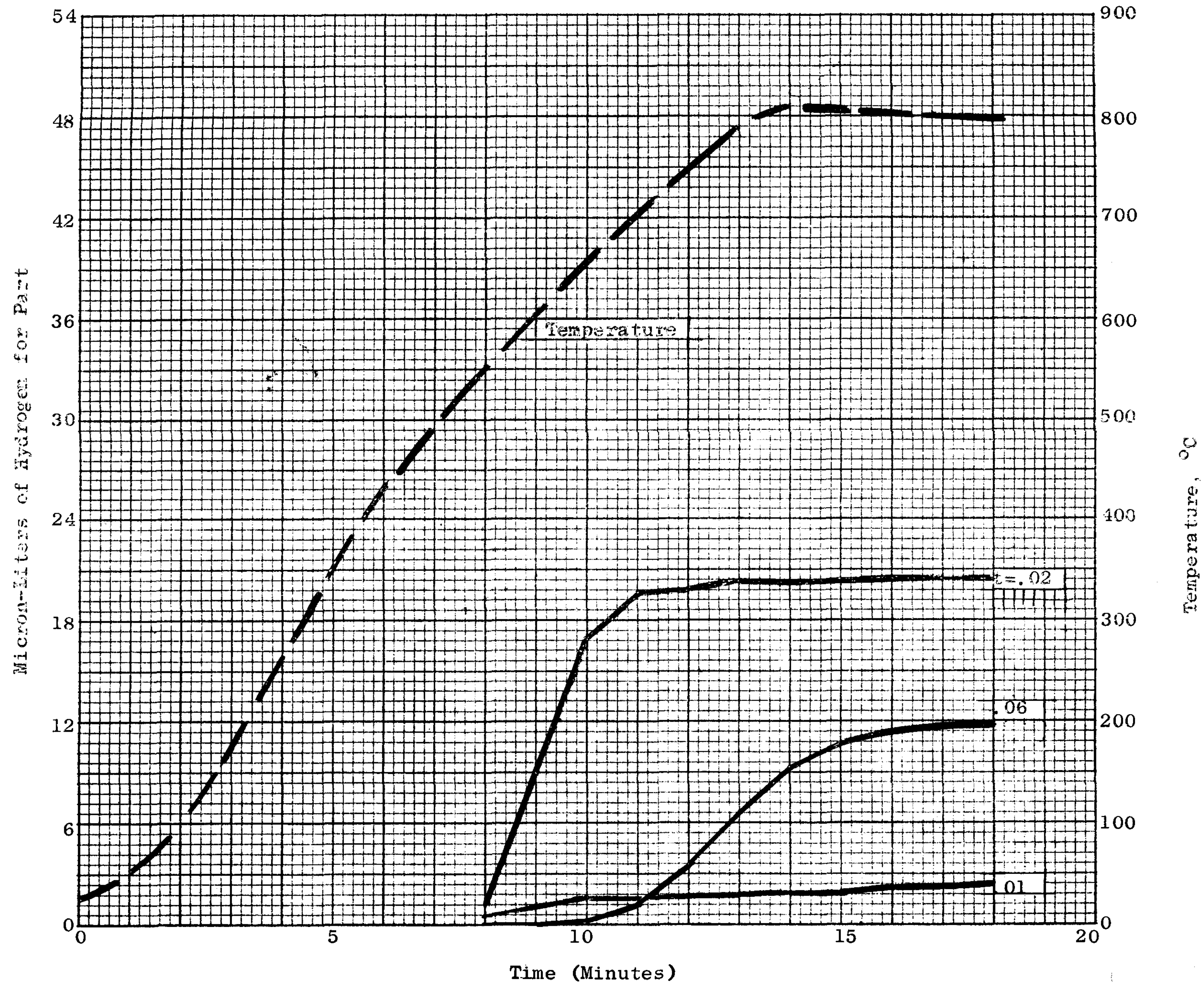


Figure 6. Results of Gas (Hydrogen) Analysis

Material: Rodar-1 Piece t(inch) thick x 1 cm. x 4 cm., As Received, Cleaned.

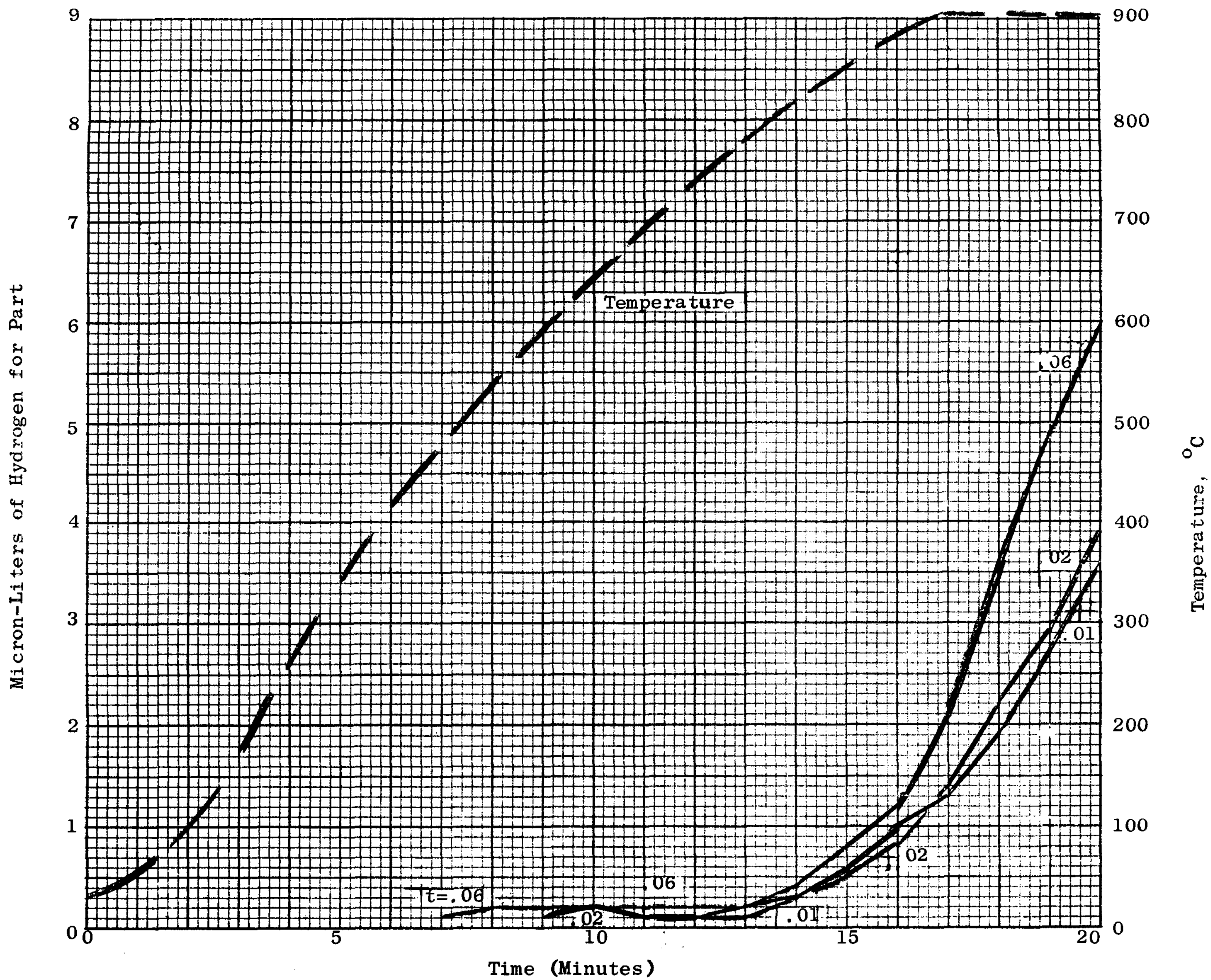


Figure 7. Results of Gas (Hydrogen) Analysis

Material: Rodar-1 Piece t(inch) thick x 1 cm. x 4 cm., Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr.

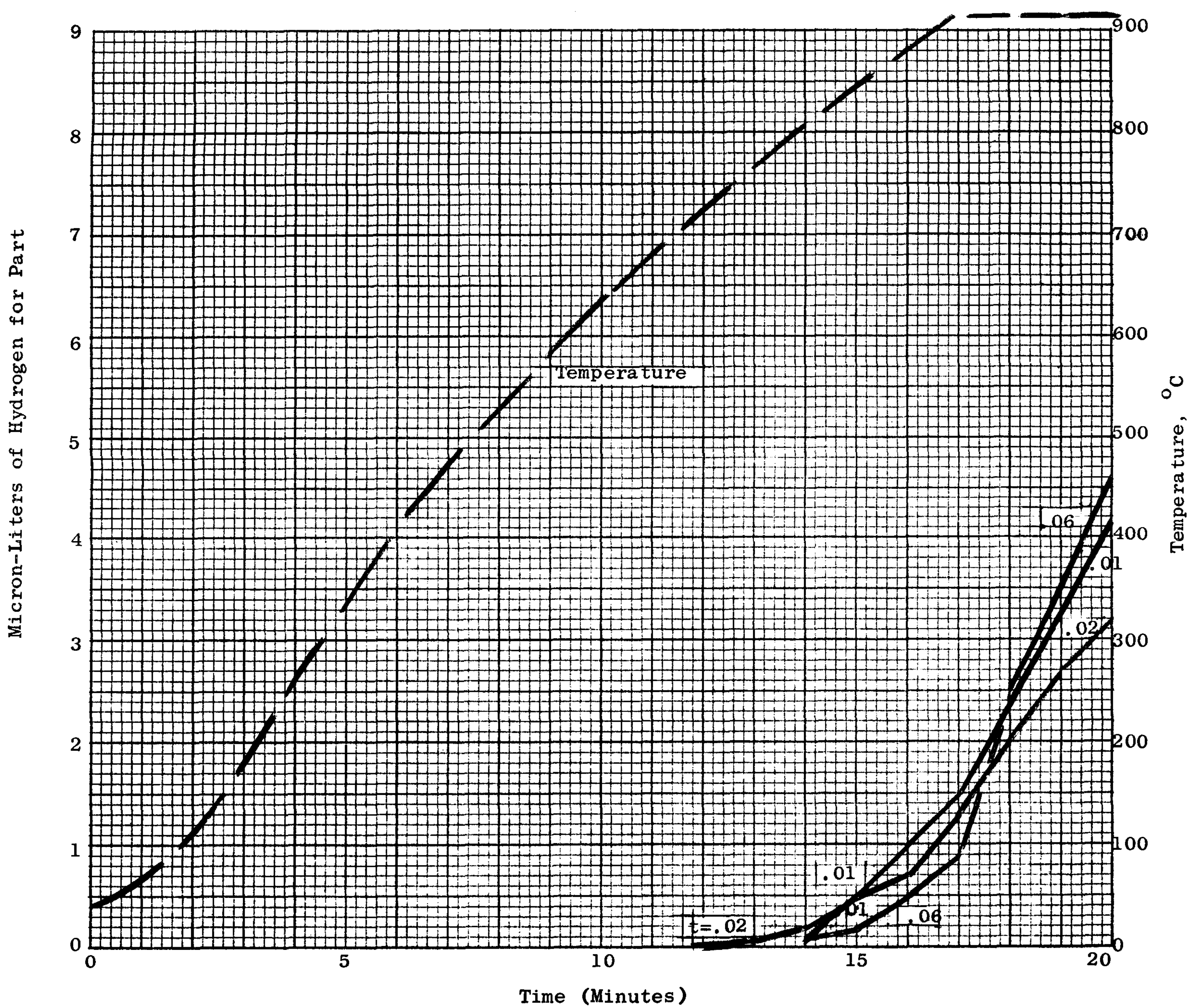


Figure 8. Results of Gas (Hydrogen) Analysis

Material: Rodar-1 Piece t(inch) thick x 1 cm. x 4 cm., Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr.

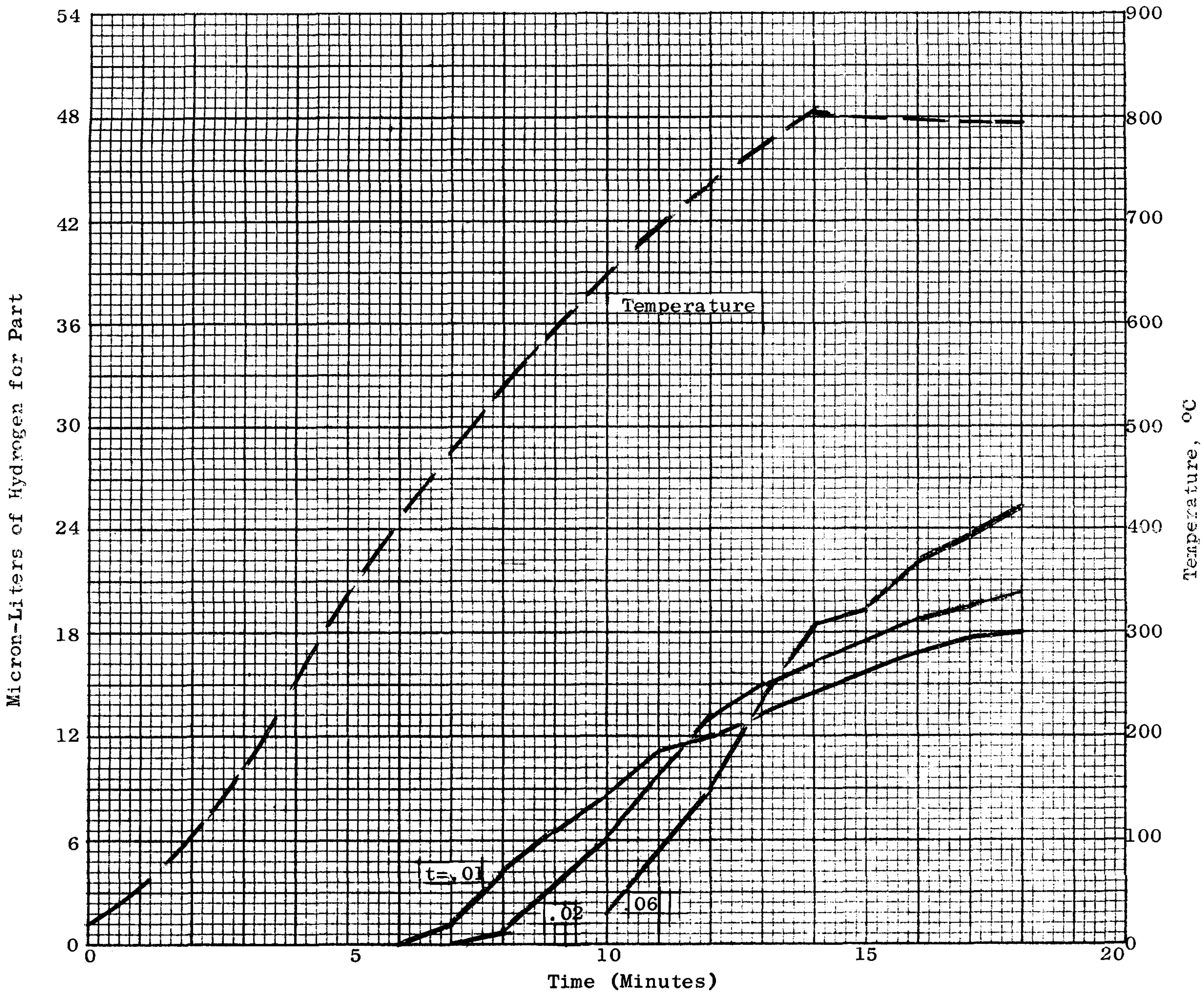


Figure 9. Results of Gas (Hydrogen) Analysis

Material: TD Nickel-1 Piece t(inch) thick x 1 cm. x 4 cm., As Received, Cleaned.

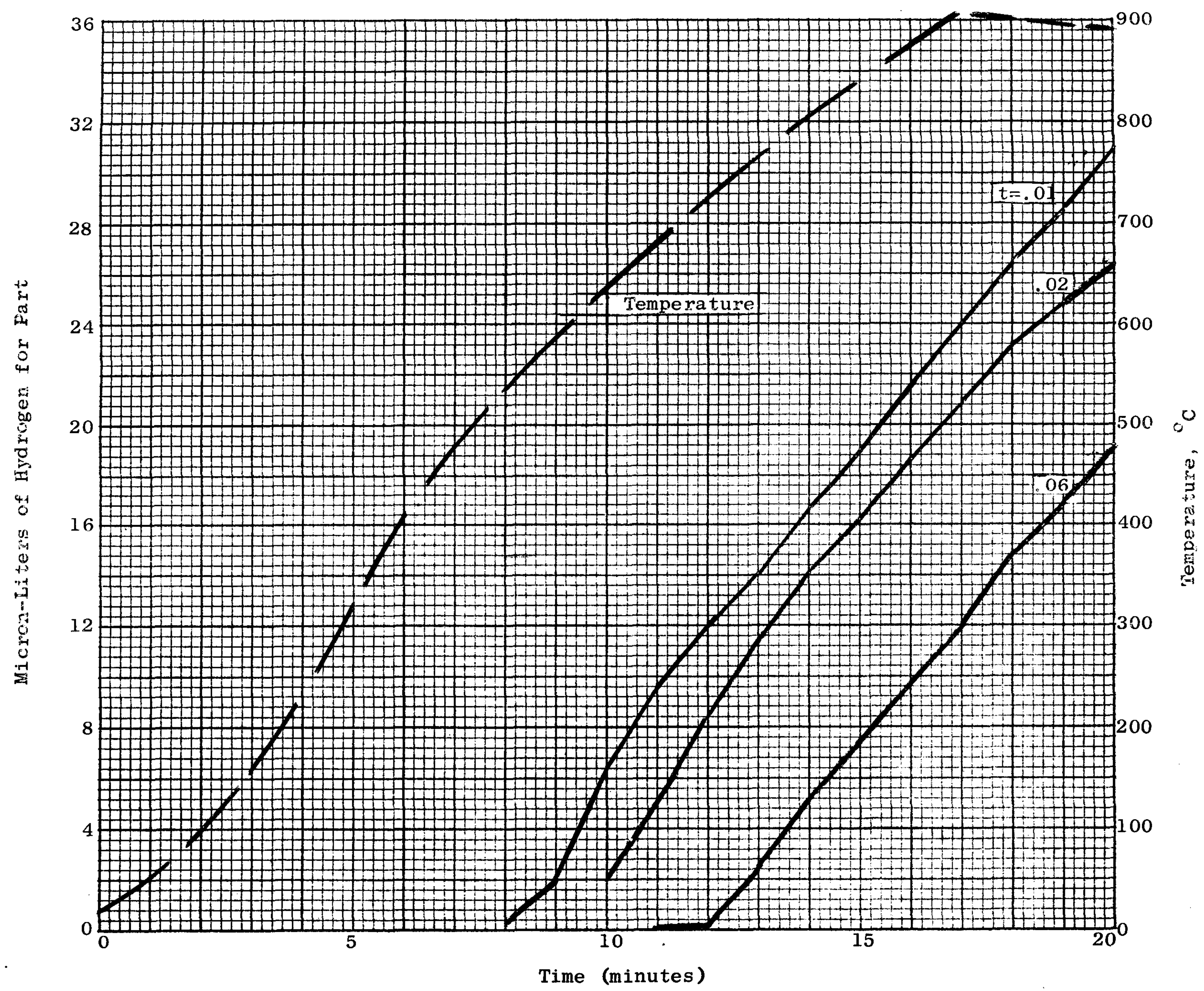


Figure 10. Results of Gas (Hydrogen) Analysis

Material: <u>TD Nickel</u>-1Piece t(inch) thick x 1 cm. x 4 cm., Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr.

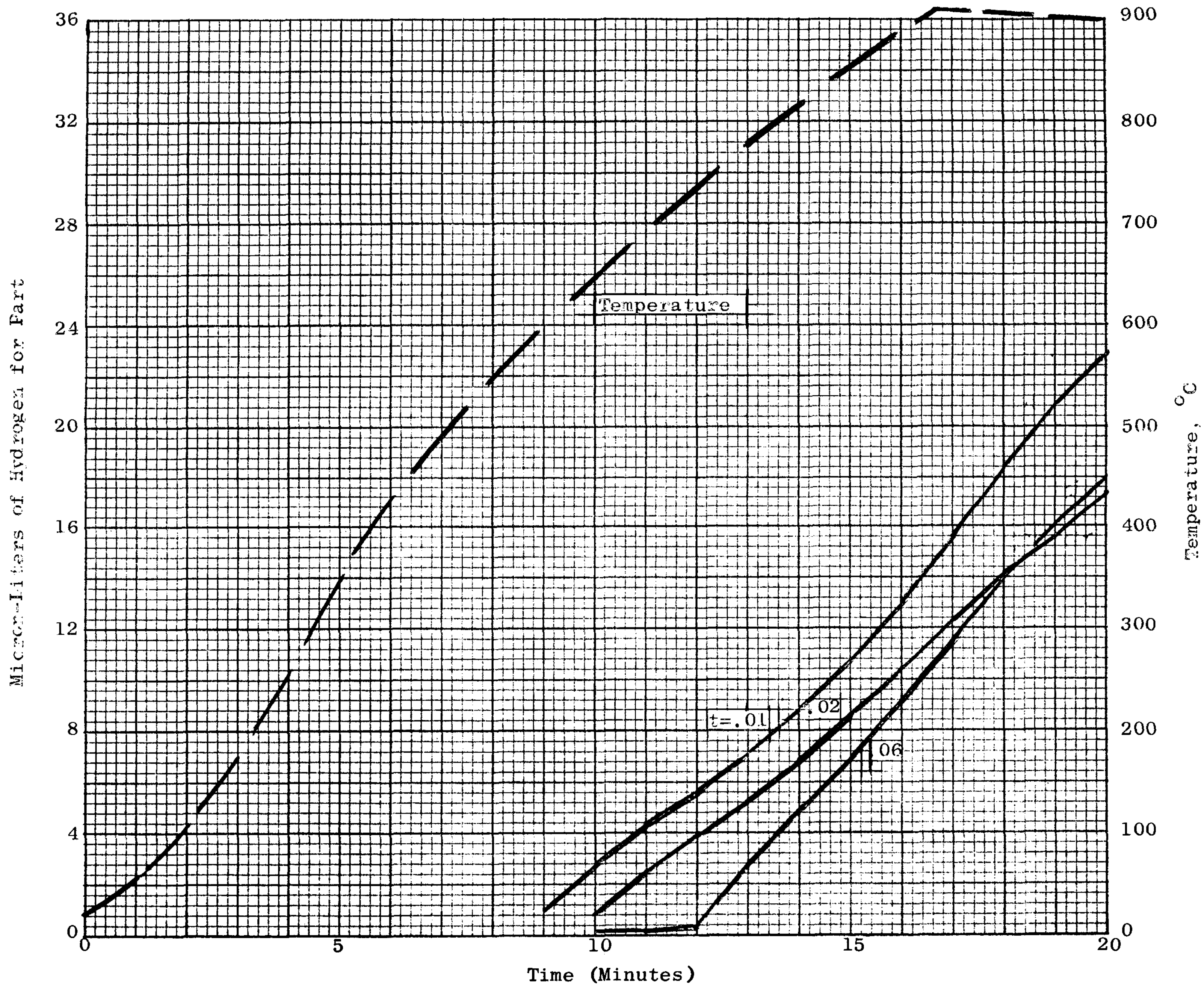


Figure 11. Results of Gas (Hydrogen) Analysis

Material: TD Nickel-1 Piece t (inch) thick x 1 cm. x 4 cm., Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr.

Figure 12. Results of Gas (Hydrogen) Analysis

Material: Titanium-1 Piece t(inch) thick x 1 cm. x 4 cm., As Received, Cleaned.

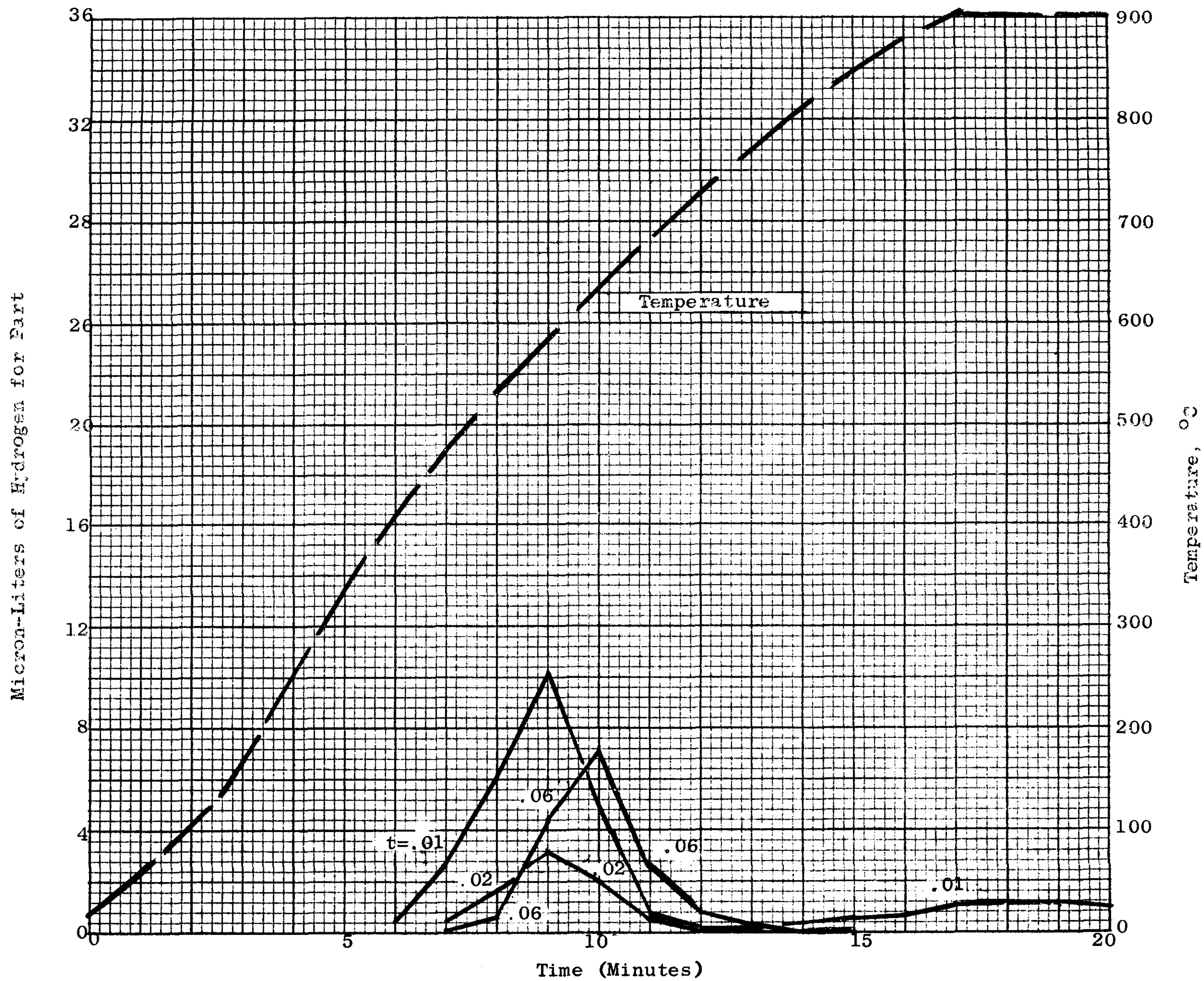


Figure 13. Results of Gas (Hydrogen) Analysis

Material: <u>Titanium</u>-1 Piece t(inch) thick x 1 cm. x 4 cm., Vac.-Fired for 6 Hours at 1550°F at 10^{-8} Torr.

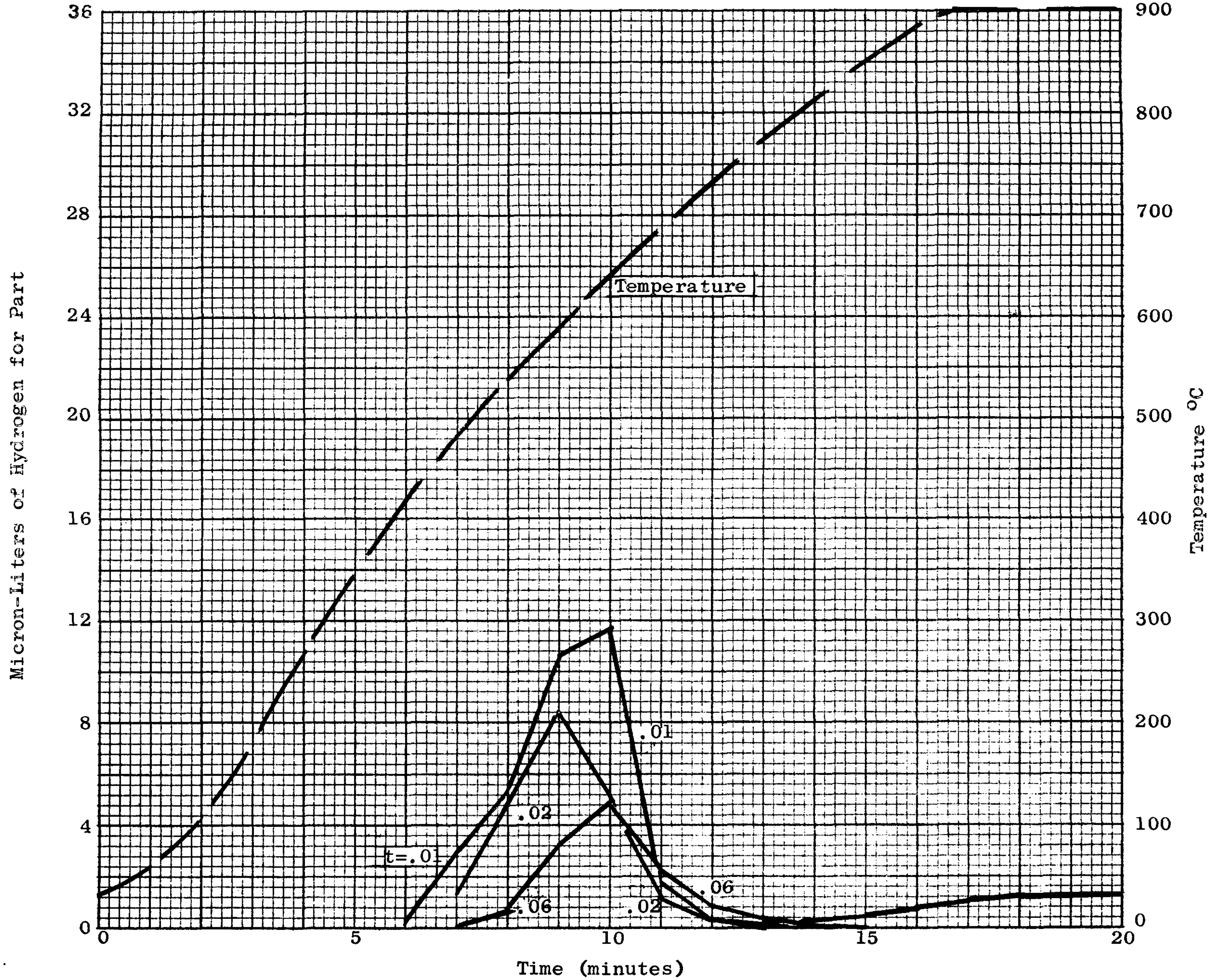


Figure 14. Results of Gas (Hydrogen) Analysis

Material: <u>Titanium</u>-1 Piece t(inch) thick x 1 cm. x 4 cm., Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr.

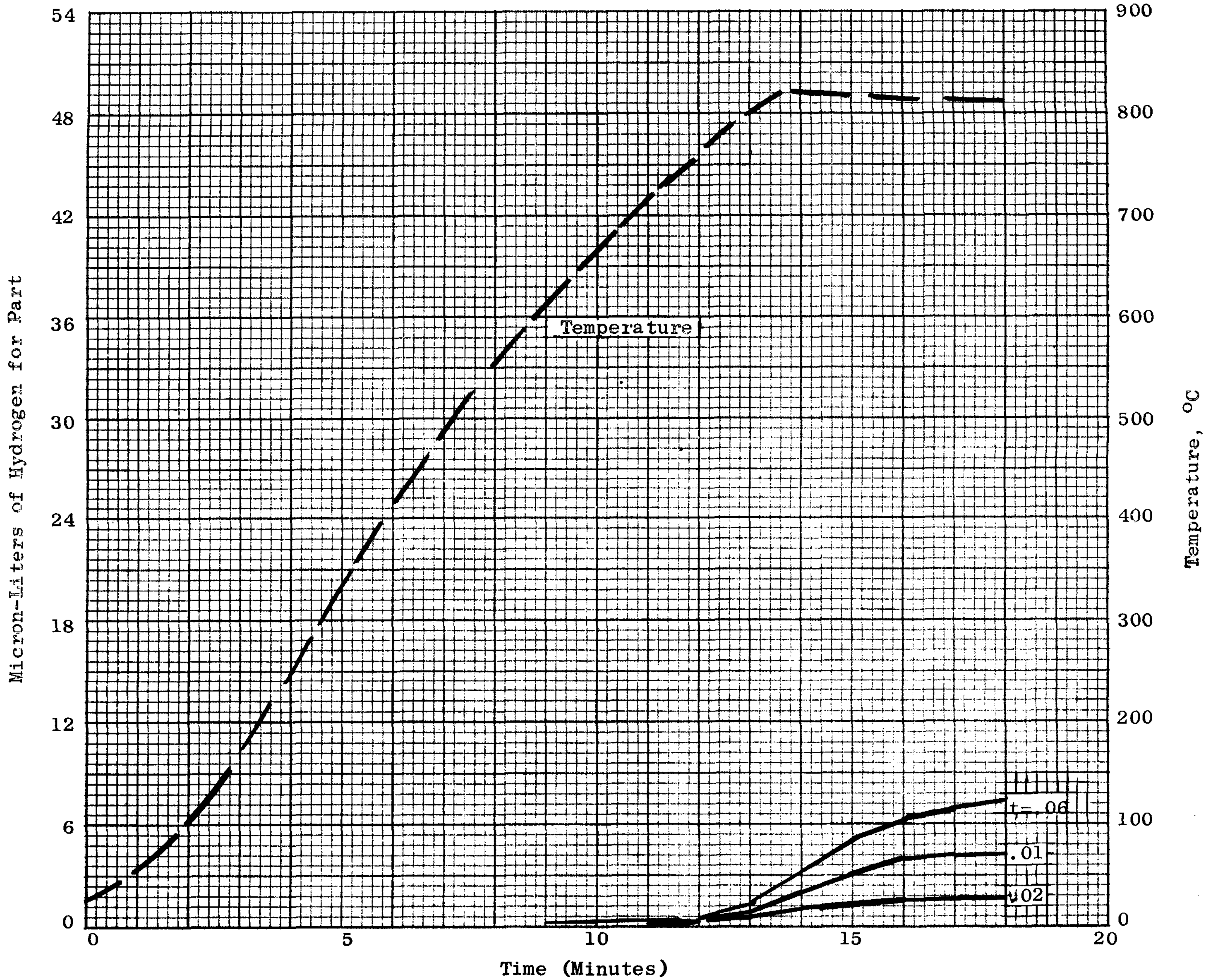


Figure 15. Results of Gas (Hydrogen) Analysis

Material: Molybdenum-1 Piece t(inch) thick x 1 cm. x 4 cm., As Received, Cleaned.

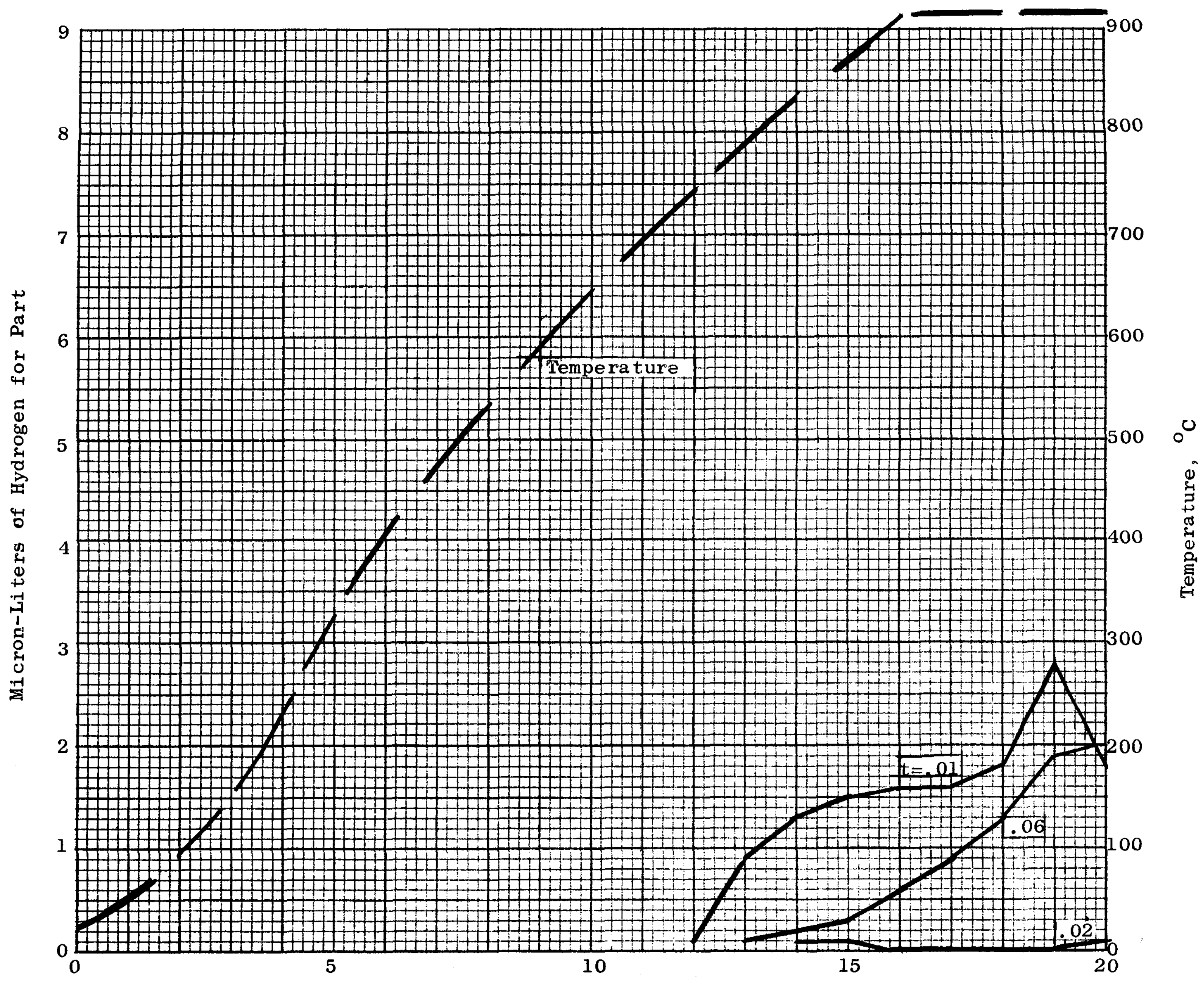


Figure 16. Results of Gas (Hydrogen) Analysis

Material: Molybdenum-1 Piece t(inch) thick x 1 cm. x 4 cm., Vac,-Fired for 6 Hours at 1550°F at 10^{-8} Torr.

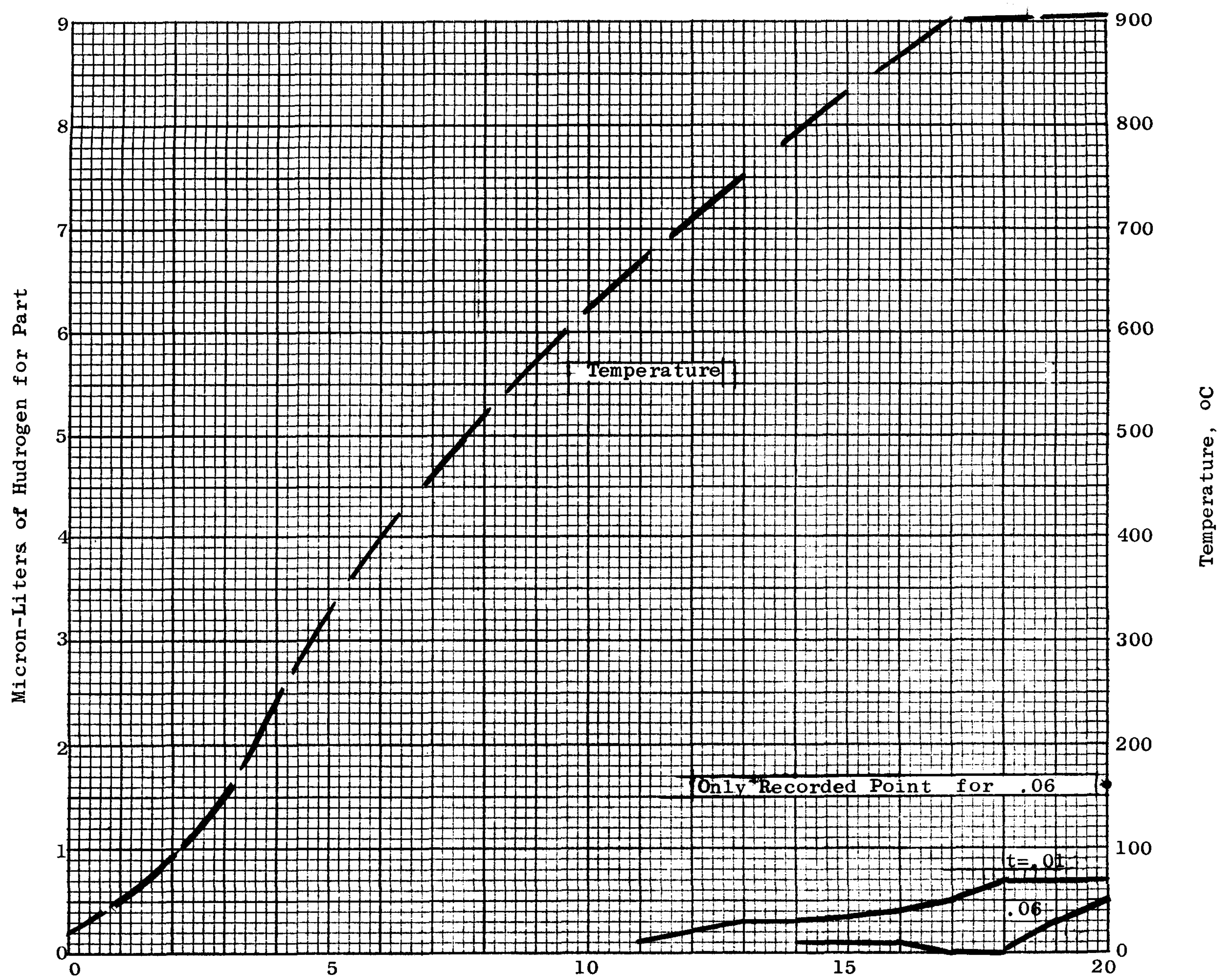


Figure 17. Results of Gas (Hydrogen) Analysis

Material: <u>Molybdenum</u>-1 Piece t(inch) thick x 1 cm. x 4 cm., Vac.-Fired for 48 Hours at 1550°F at 10^{-8} Torr.

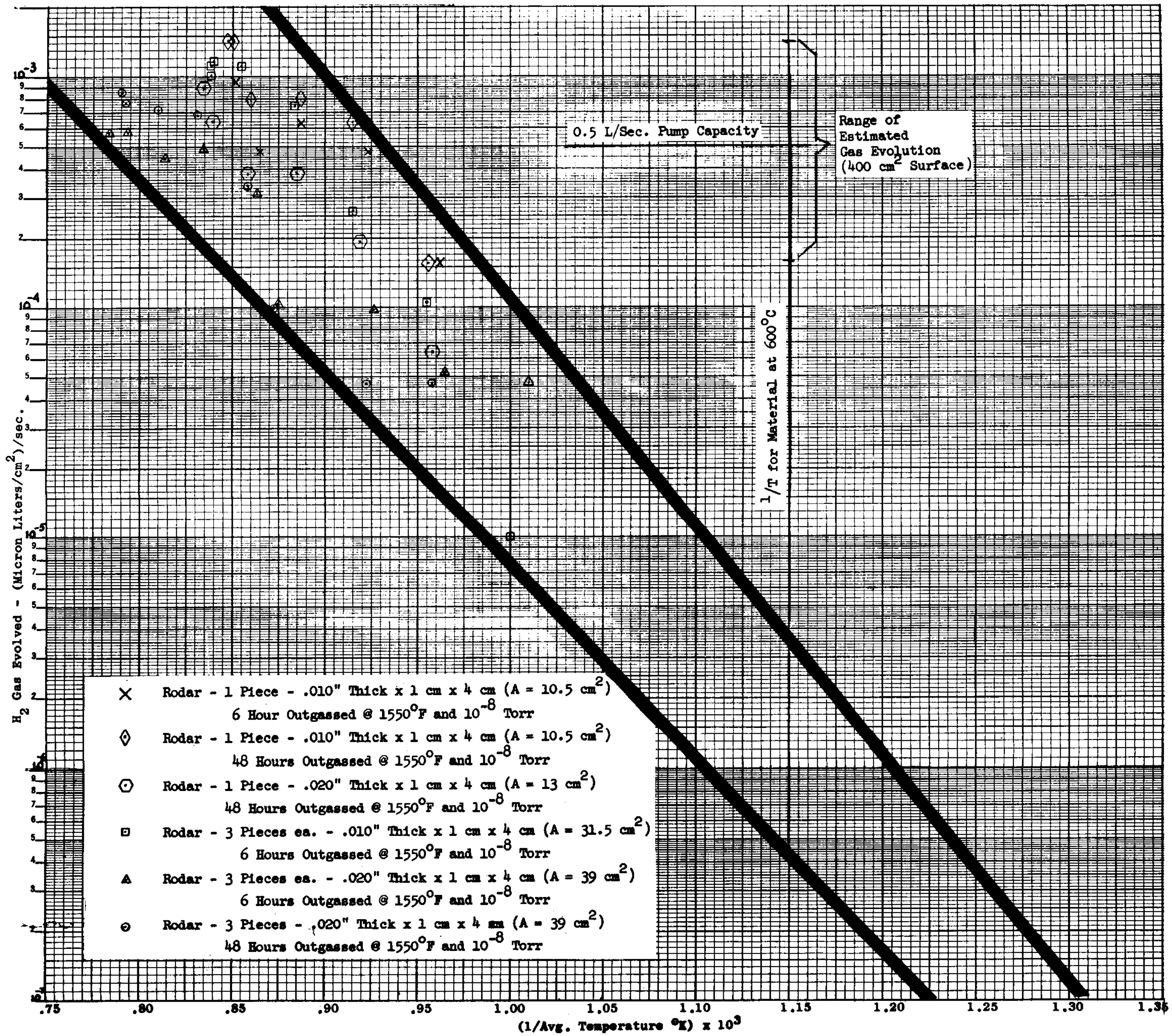


Figure 18 : Switch Material (RODAR) Hydrogen Gas Evolution Rates

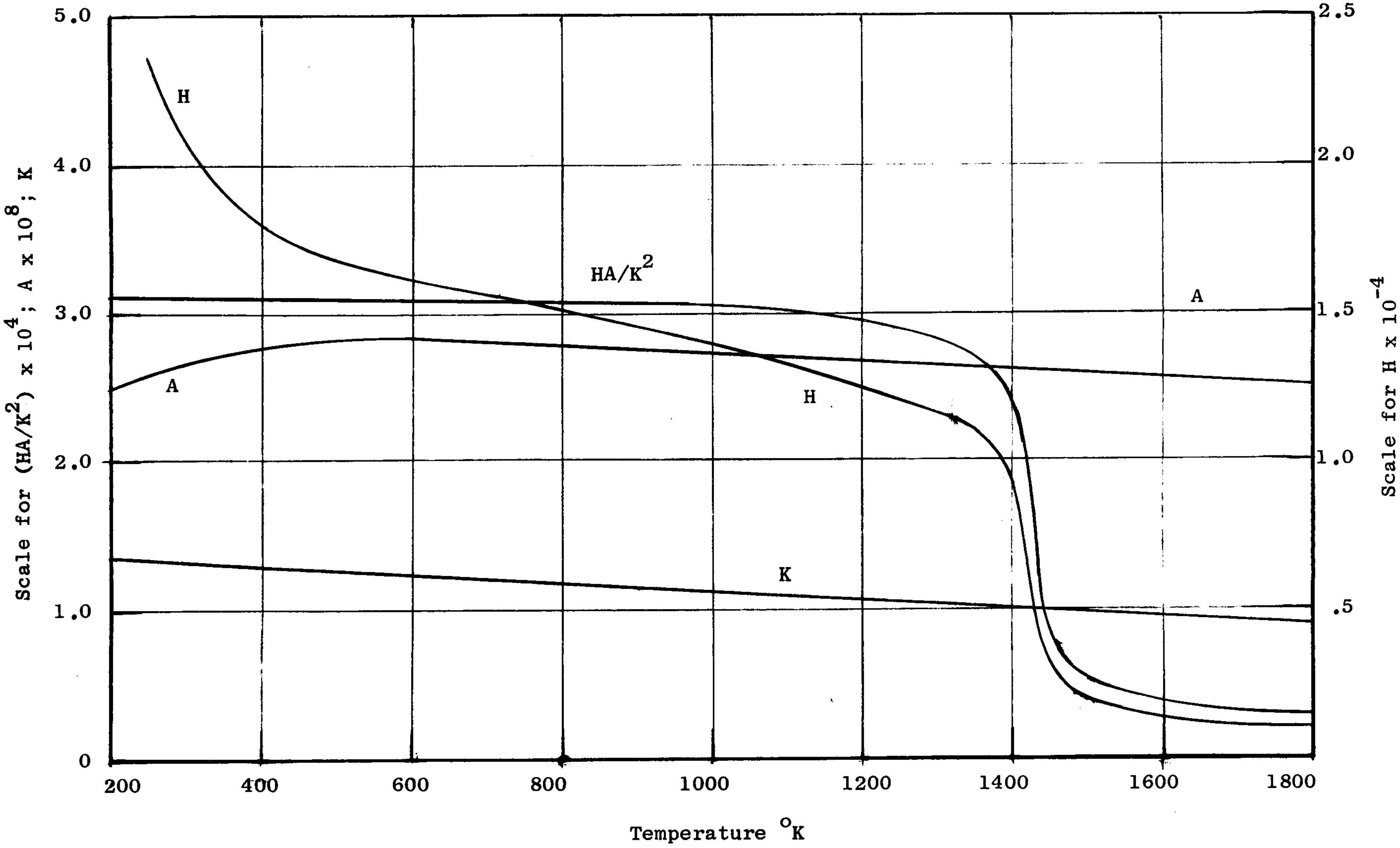


Figure 19: Molybdenum Contact Parameters as Related to Temperature

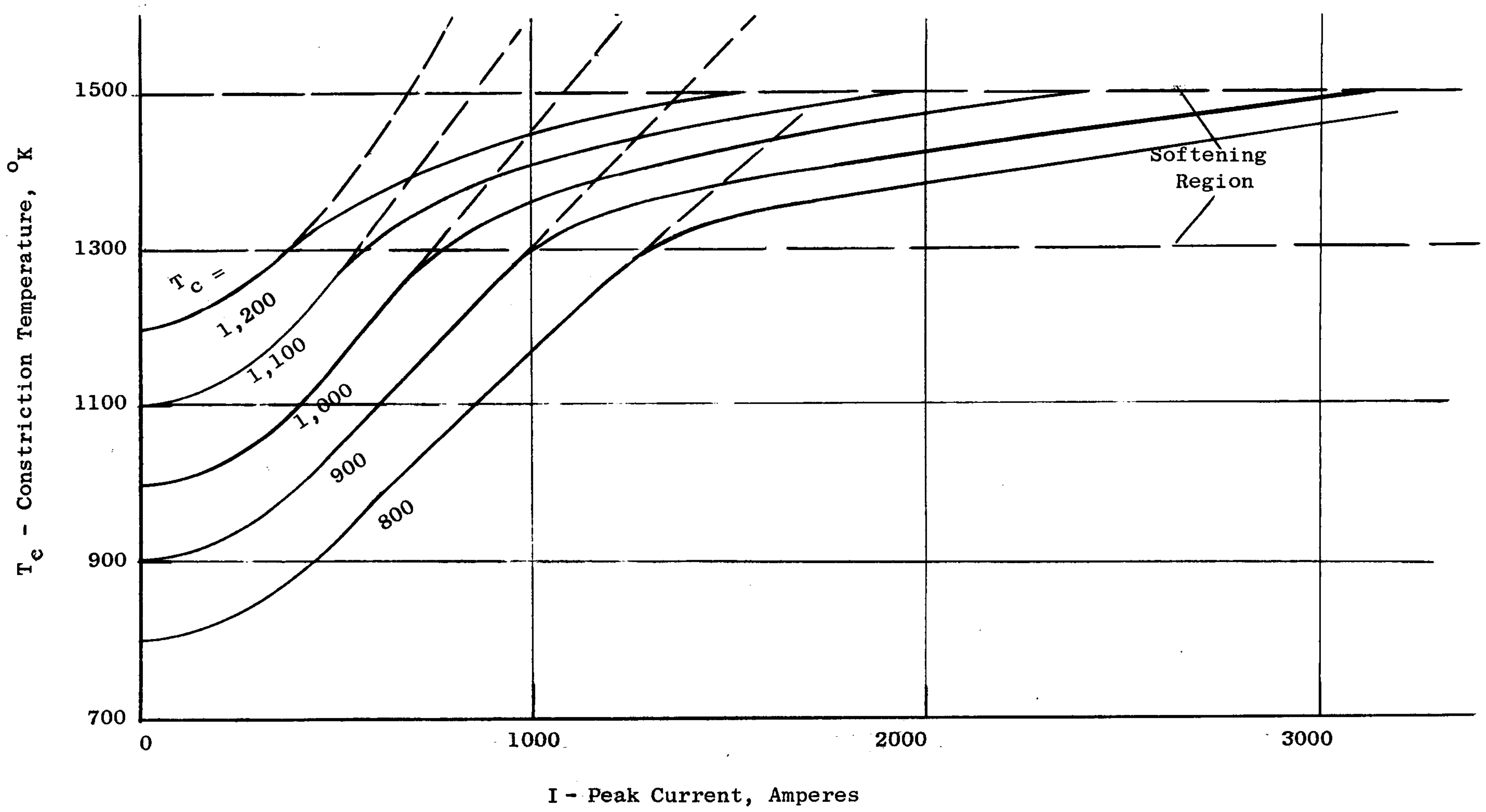


Figure 20: Constriction Temperature Variation with RMS Current

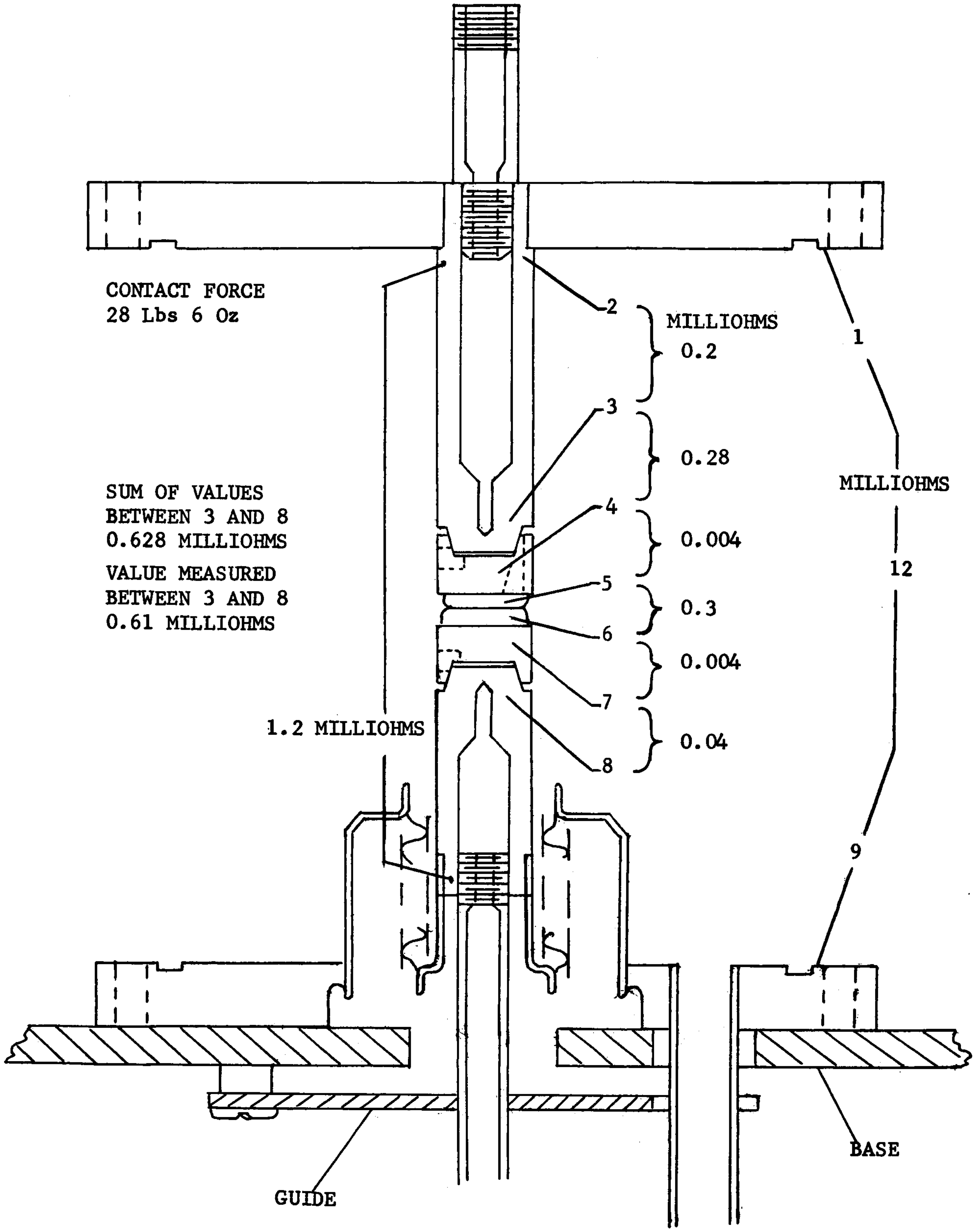


Figure 21: Resistance of Contact Structure in Phase I Demountable Capsule.

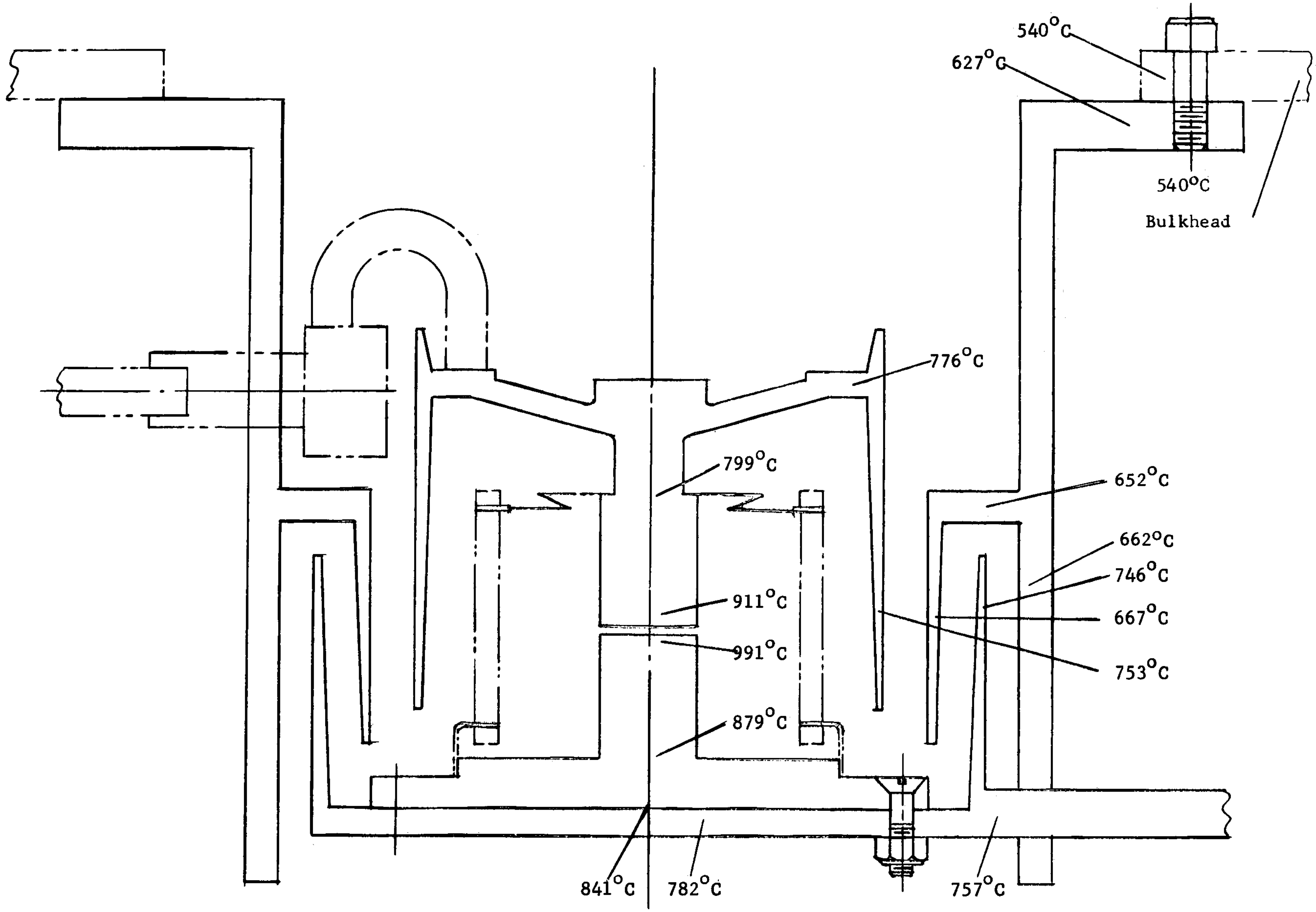


Figure 22: Calculated Temperatures for Vacuum Interrupter of Original Design with Radiators.

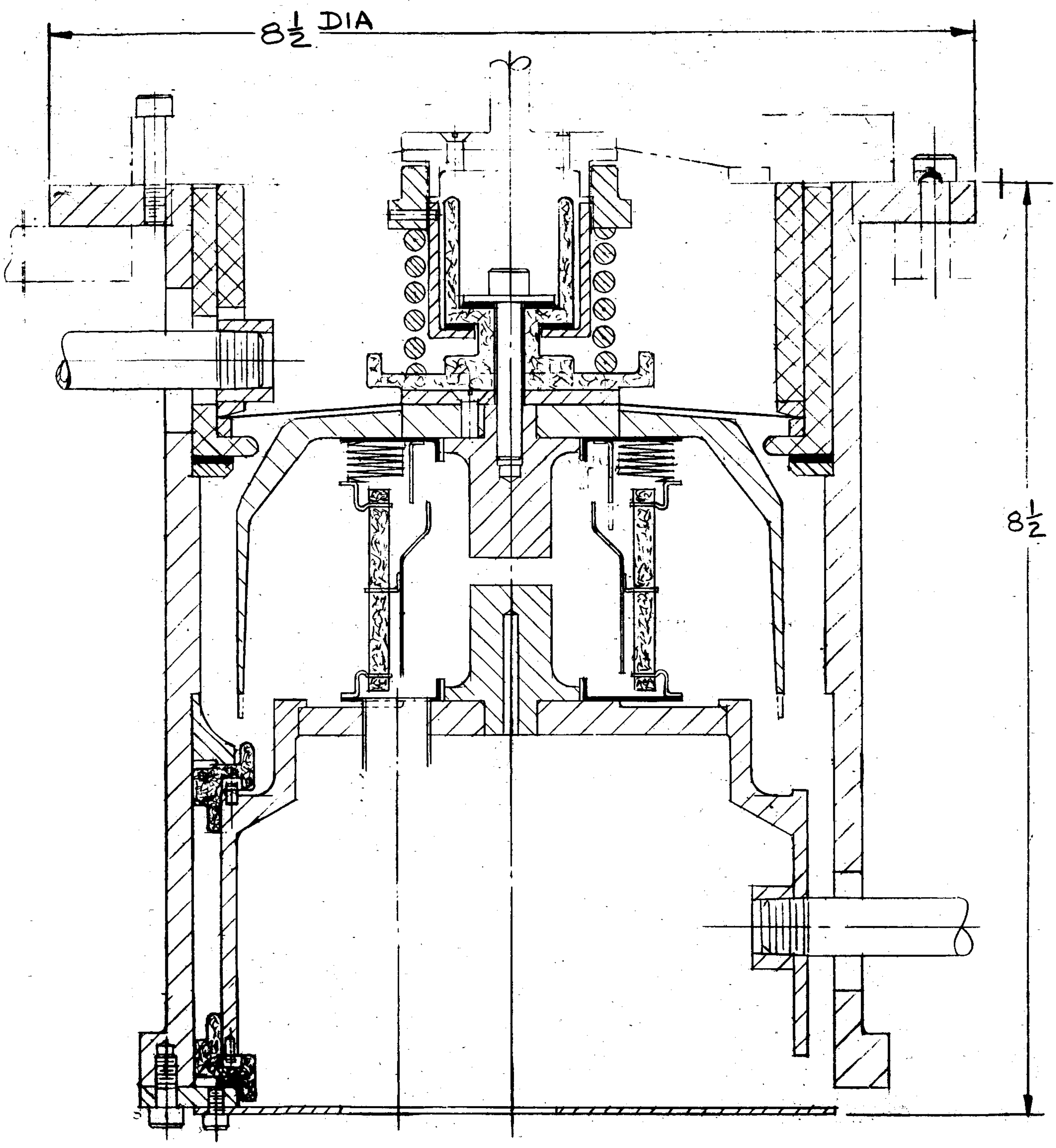


Figure 23: Advanced Design Concept for AC Vacuum Interrupter with Heat Radiators.

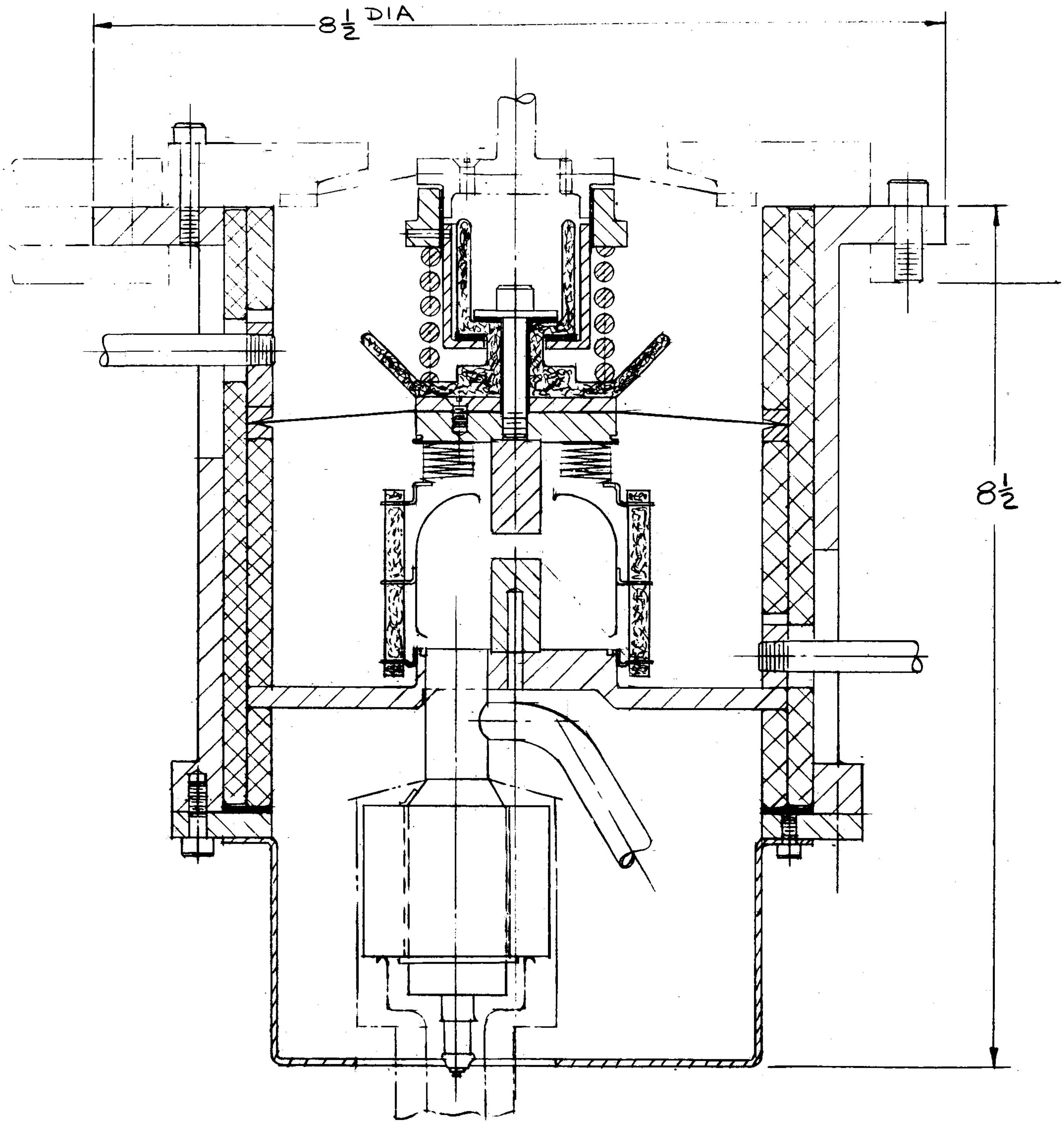


Figure 24: Design Concept for DC Engine Contactor Vacuum Interrupter.

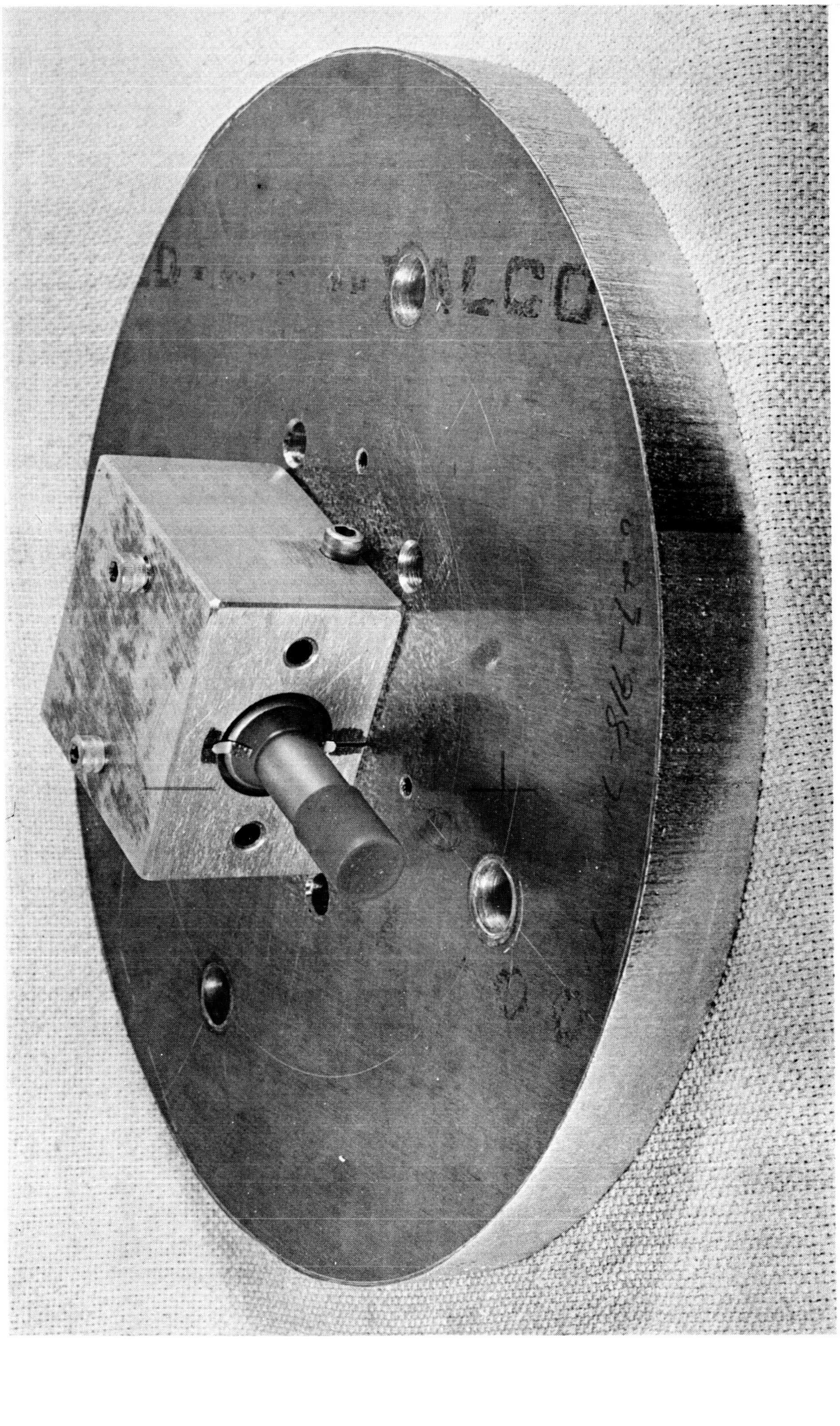


Figure 25: Ion Pump Element in Vibration Test Fixture.

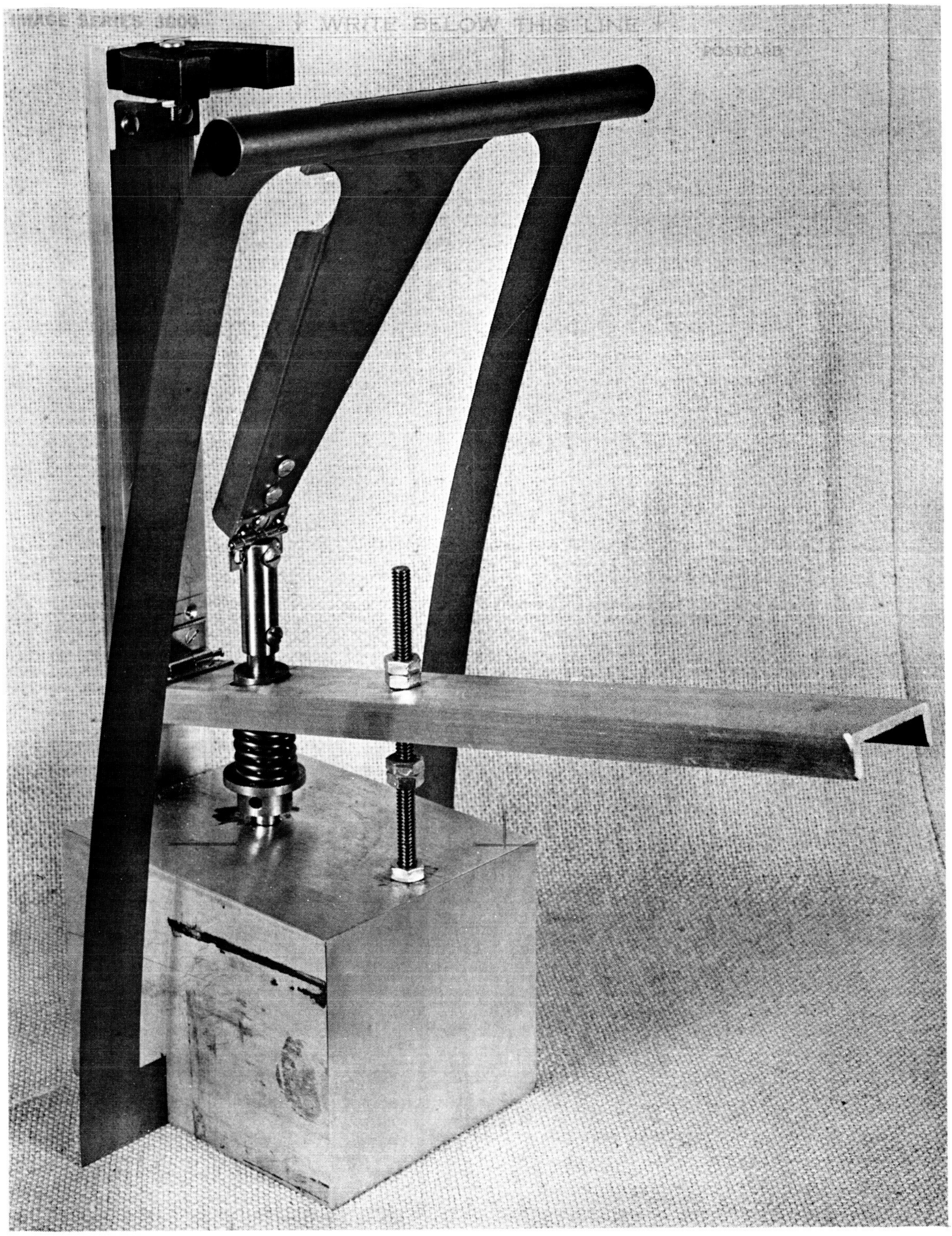


Figure 26: "Mock-up" of Reverse Toggle Actuator Linkage.

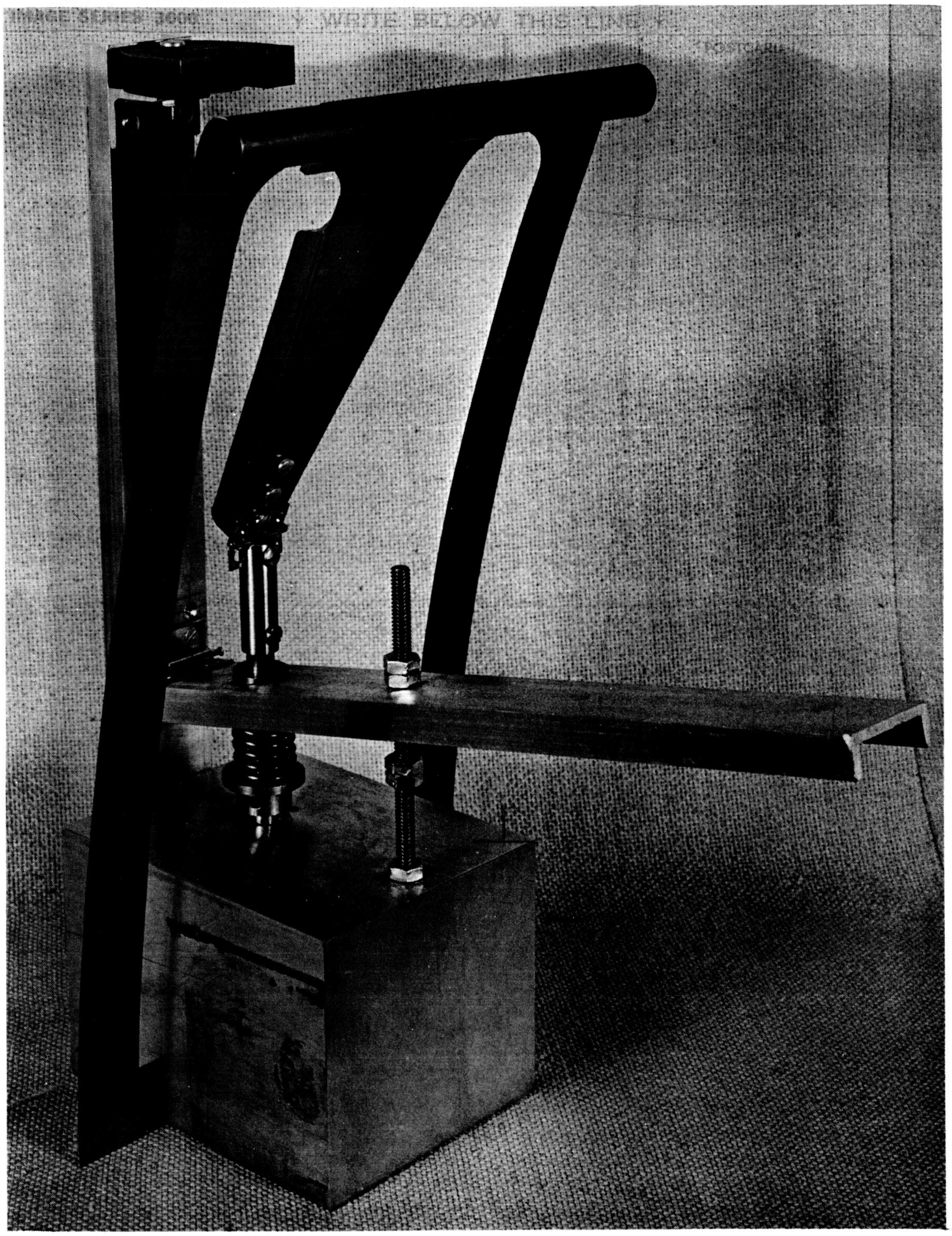


Figure 26: "Mock-up" of Reverse Toggle Actuator Linkage.

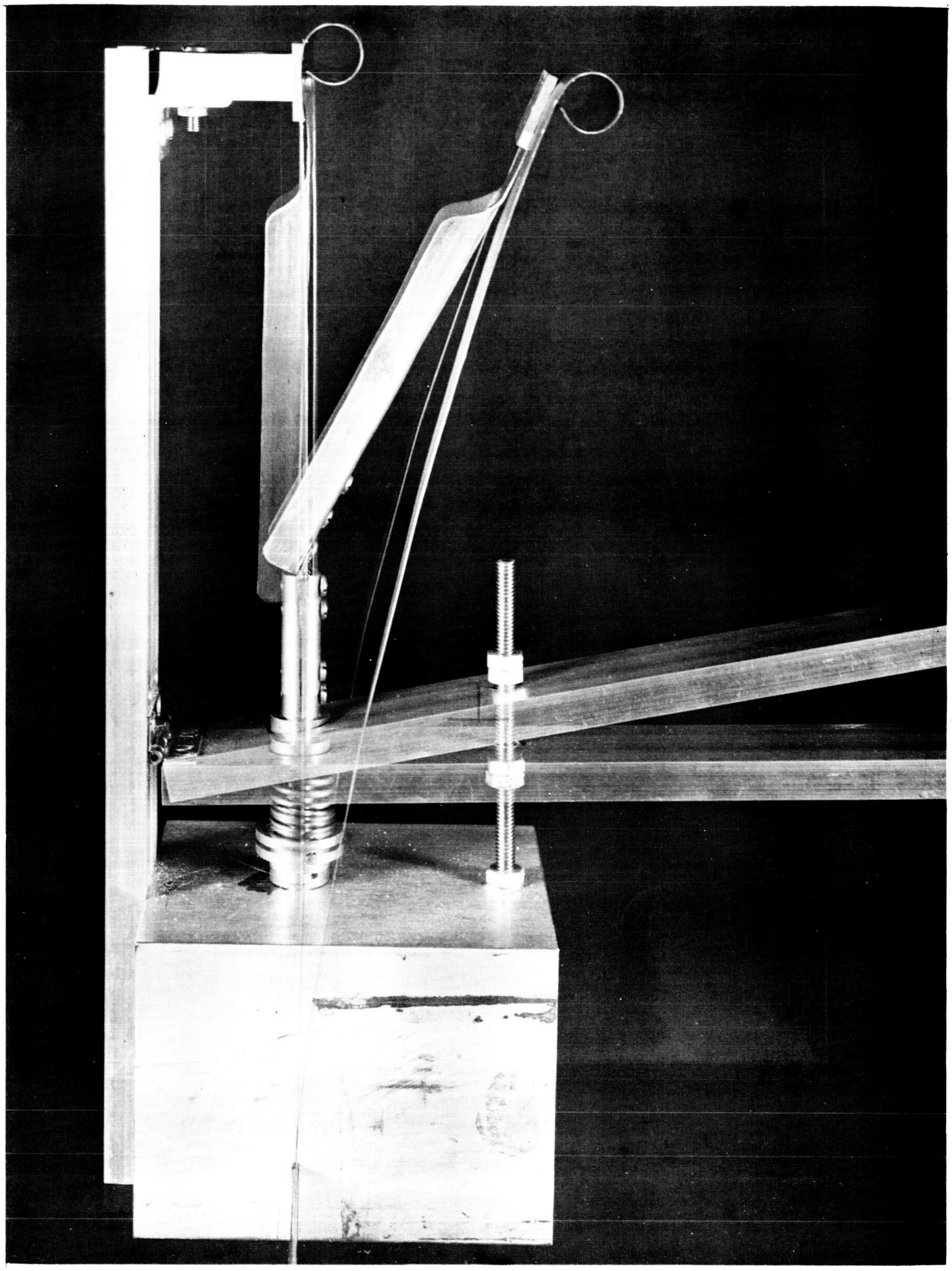


Figure 27. Reverse Toggle Actuator Linkage in Closed and Open Positions.

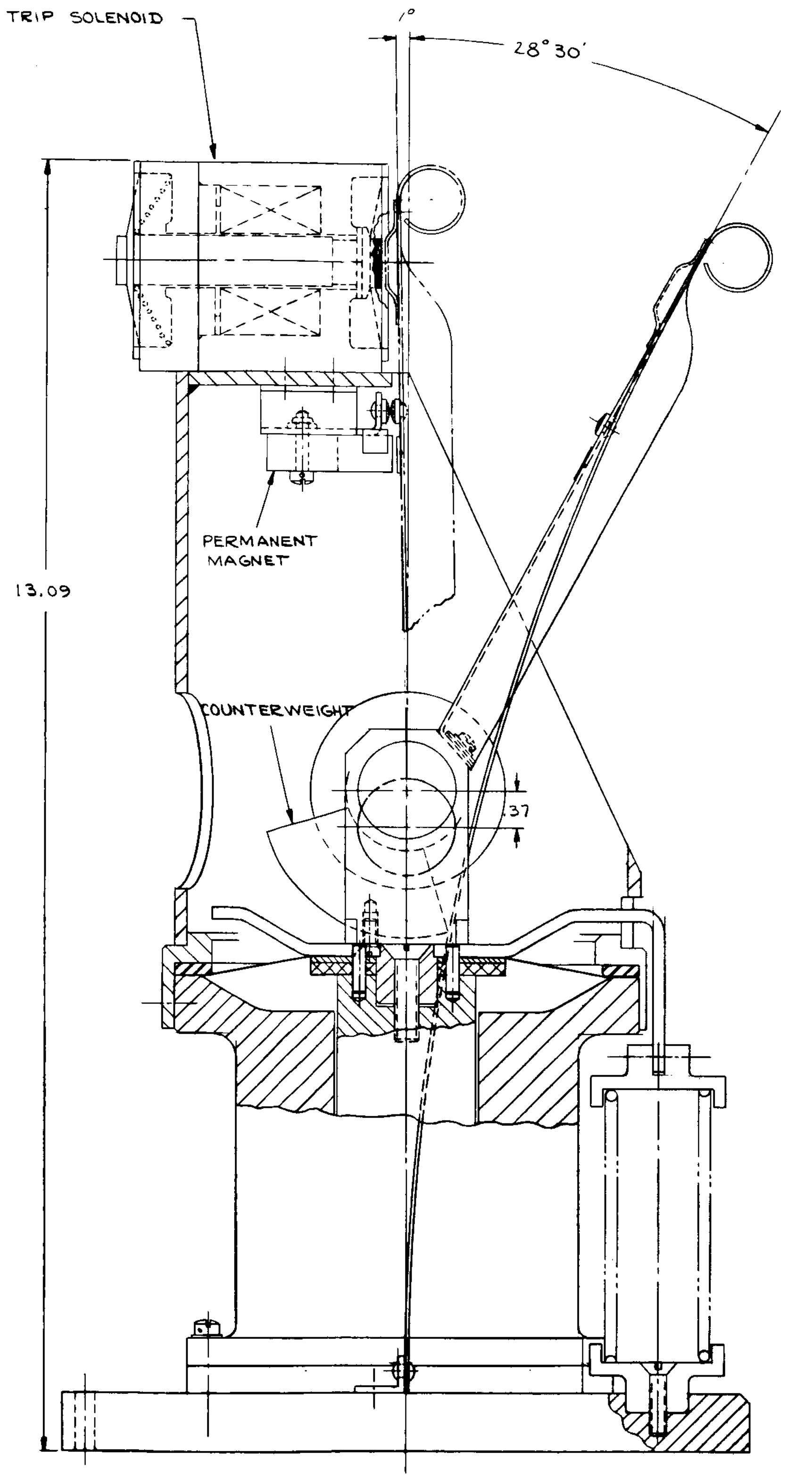


Figure 28: Layout of Mechanism Showing the Side View.

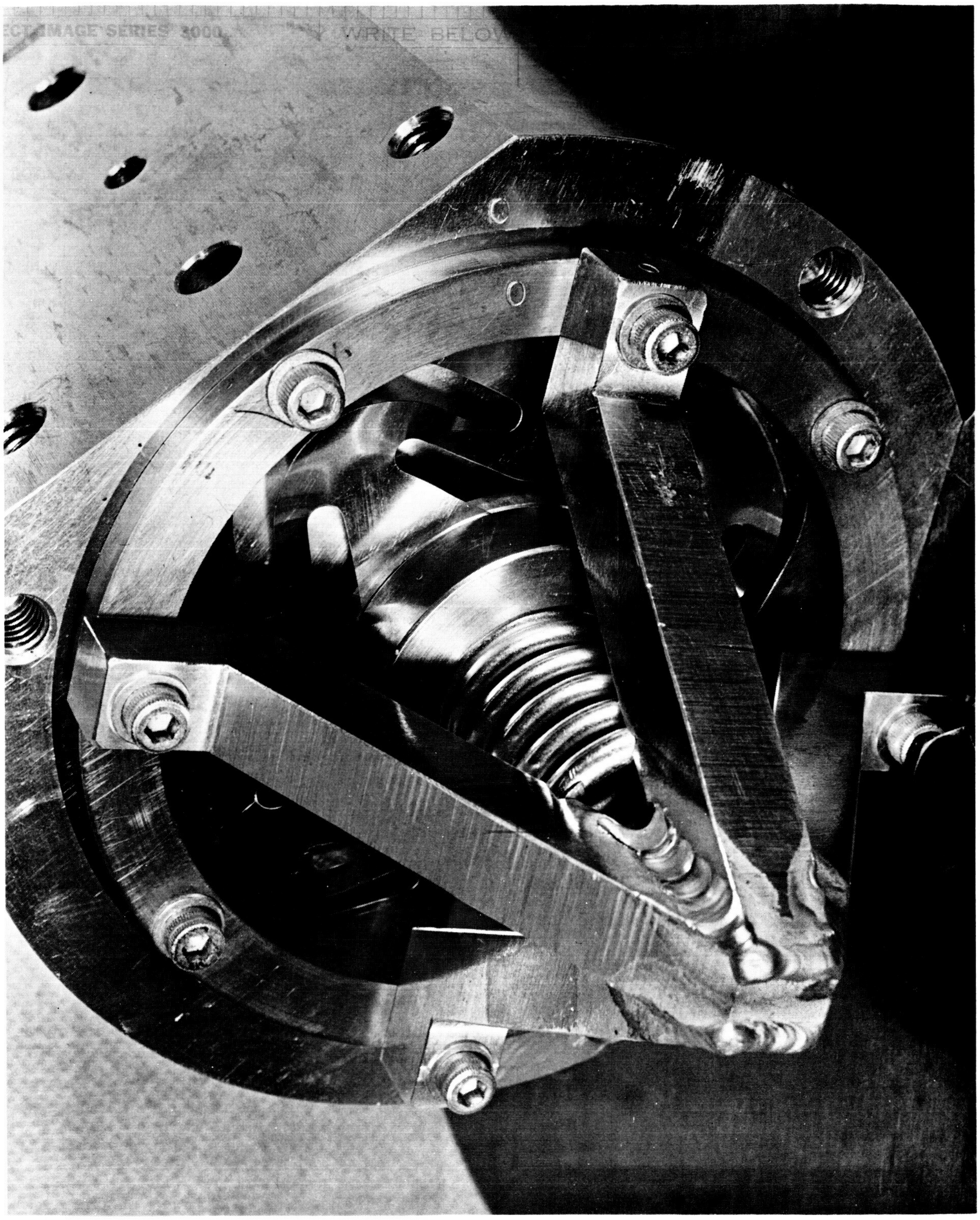


Figure 29: Solenoid Diaphram in Vibration Test Fixture.

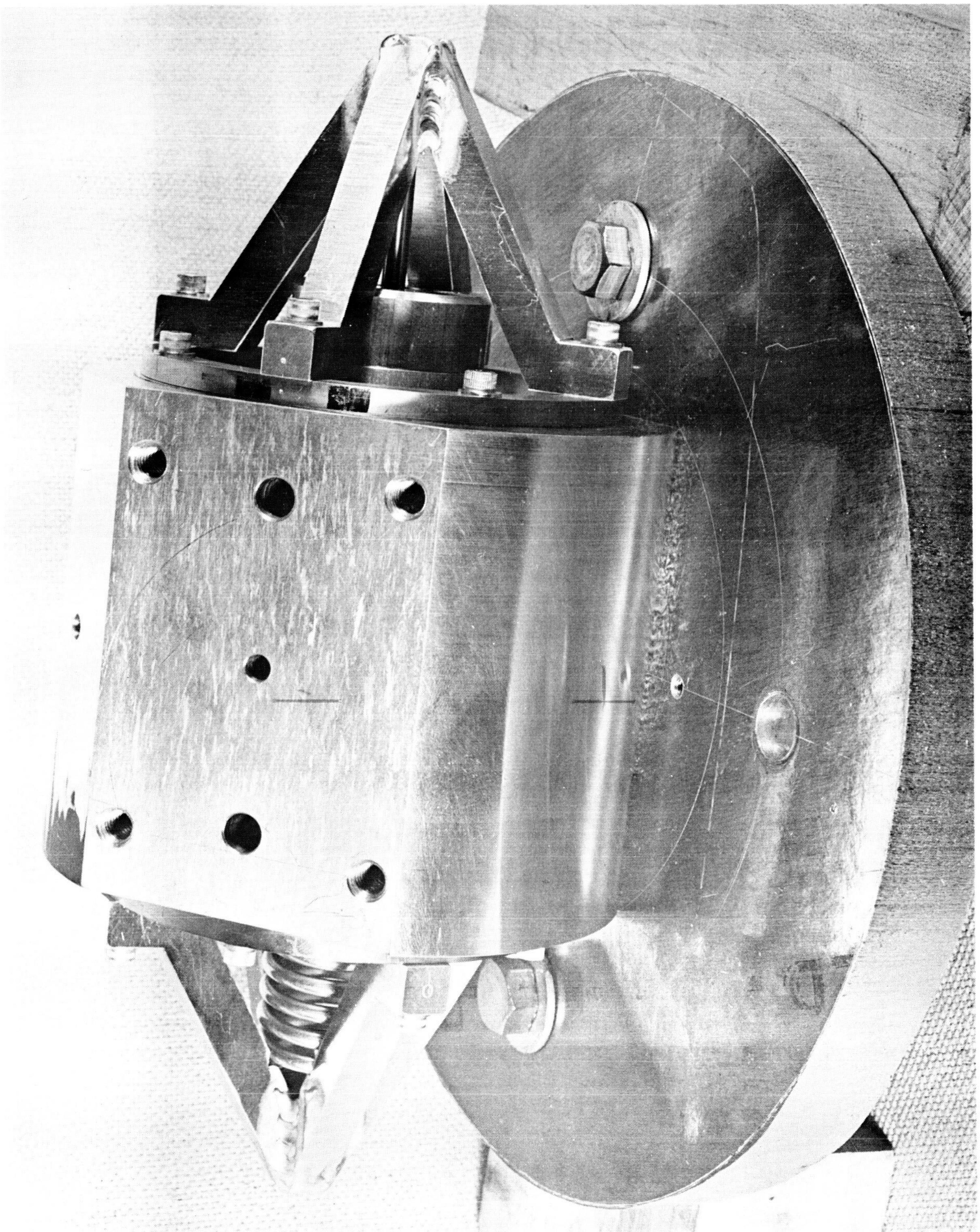


Figure 30: Diaphram Vibration Test Fixture Set-up for Radial Vibration.

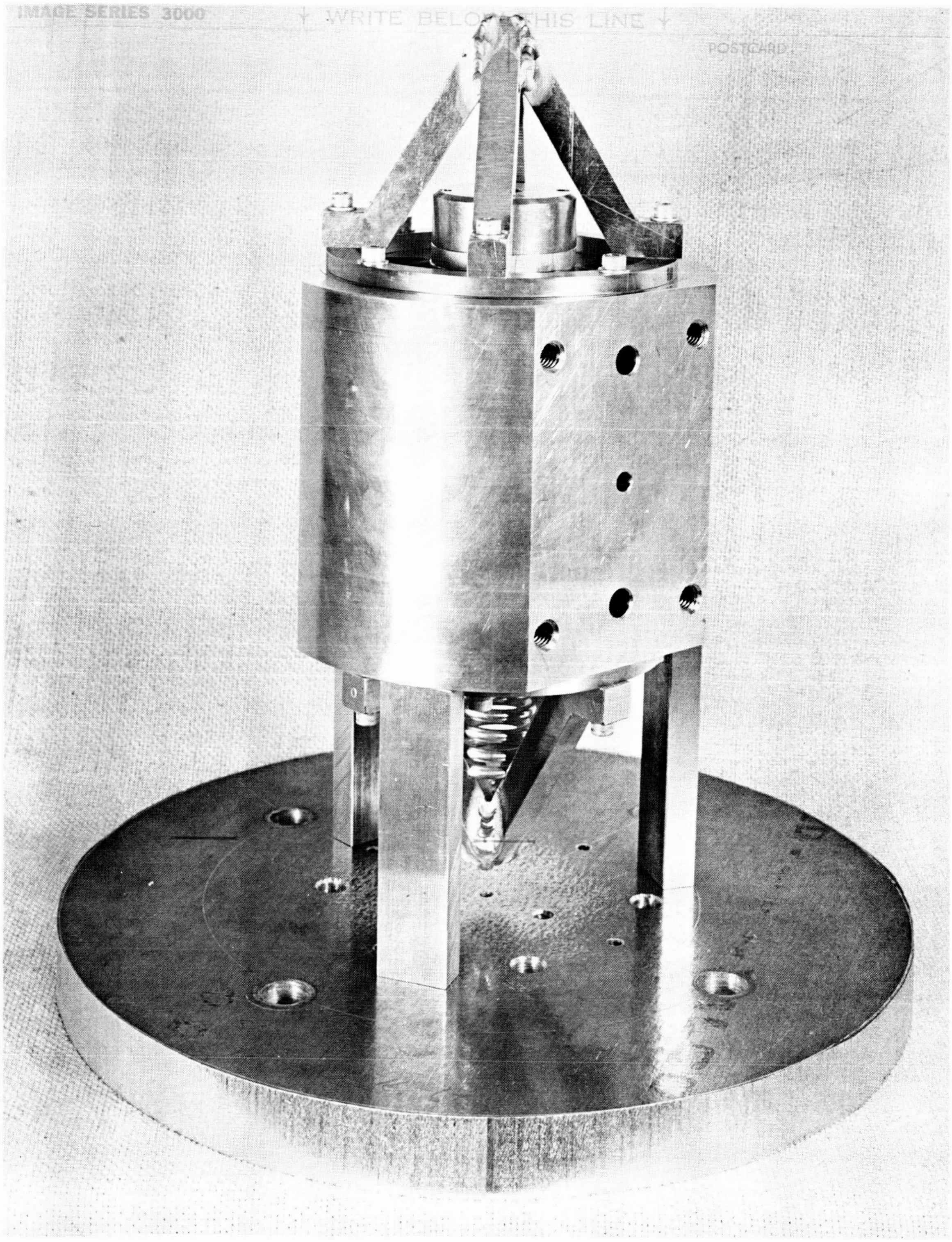
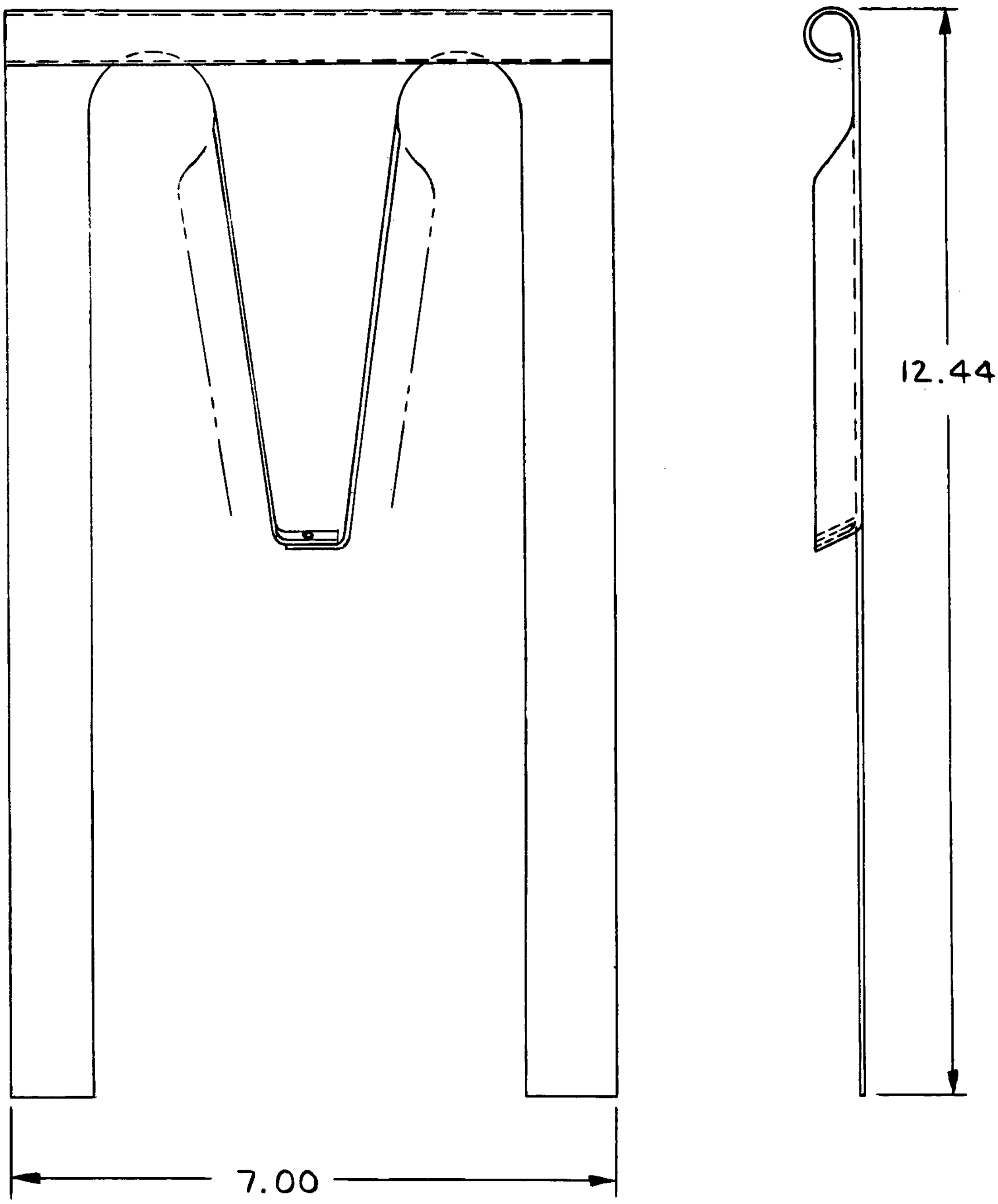


Figure 31: Diaphram Vibration Test Fixture Set-Up for Axial Vibration.



Material - 0.020 Thick Inconel-X Type 750
Huntington Alloy Products
Huntington, W. Virginia

Figure 32: Actuator Linkage Layout

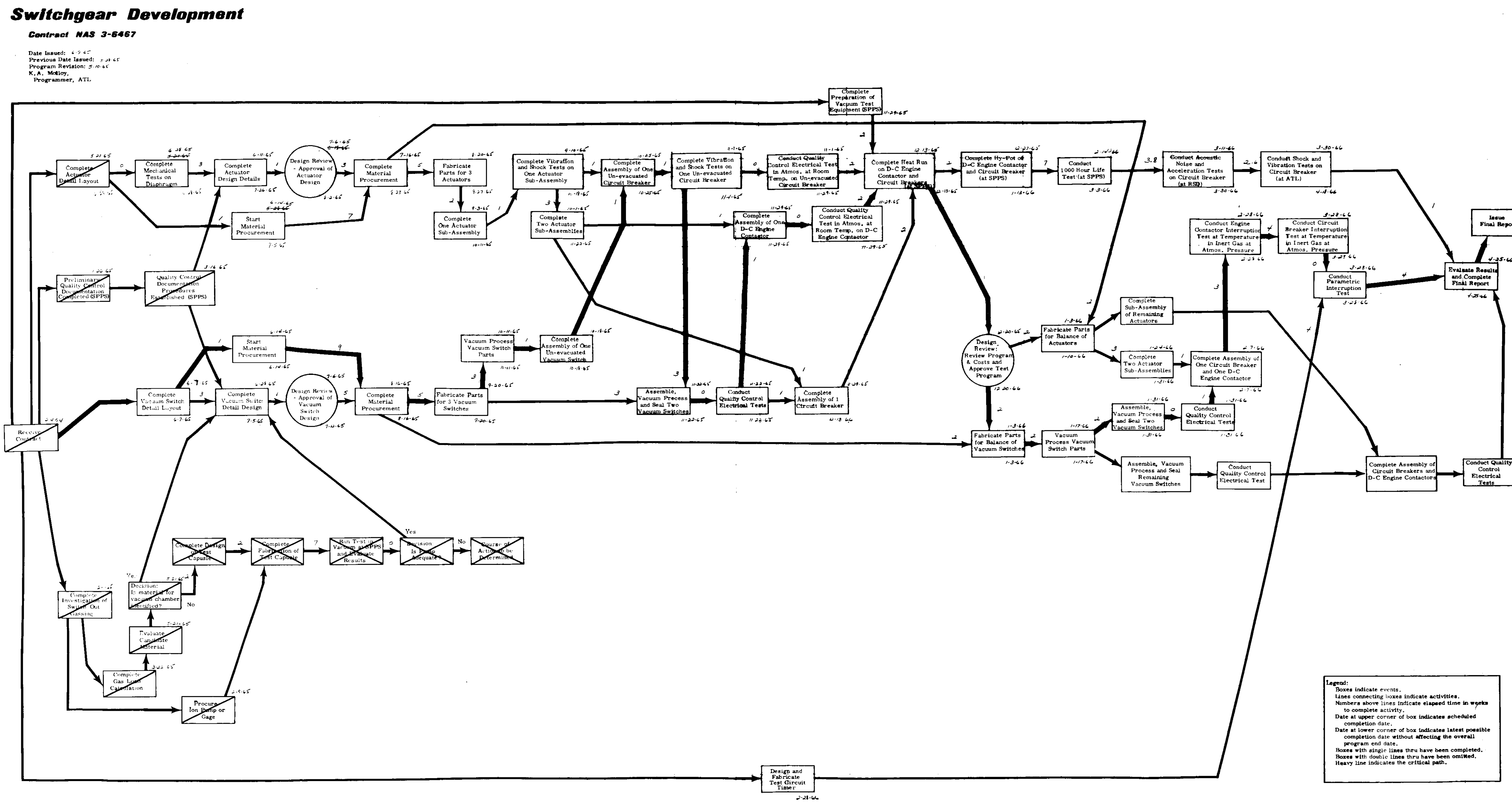


Figure 33: PERT Diagram

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